AN EMPIRICAL ASSESSMENT OF FACTORS PRECLUDING RECOVERY OF SAUGER IN THE LOWER YELLOWSTONE RIVER: MOVEMENT, HABITAT USE, EXPLOITATION, AND ENTRAINMENT

by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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This thesis is dedicated to Rob Van Kirk for showing me how to make a difference and to Jim Gregory for teaching me how to "get after it!" Their examples were not only motivational in my research but have allowed me a glimpse of the type of person I hope to become professionally and personally.

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ABSTRACT

Sauger (*Sander canadensis*) were designated as a critically imperiled Species of Special Concern in Montana because of declines in distribution and abundance. Migratory barriers, habitat loss, entrainment in irrigation canals, and overexploitation, especially at times when sauger were aggregated, were suggested to explain the failure of Yellowstone River sauger to return to historical abundances. I characterized seasonal movement patterns, habitat use, and aggregation of sauger and estimated movement, exploitation, and Intake Canal entrainment rates to test these hypotheses. Seasonal movement, aggregation, and habitat use were investigated by telemetering and tracking 30 fish in 2001, 31 fish in 2002, and 30 fish in 2003. Exploitation and entrainment rates were assessed by tagging 957 sauger with reward tags. Tag-shedding rate (2.1%) was estimated by double-tagging and non-reporting rate (61.5%) was estimated using postcards as tag surrogates. Sauger aggregated near spawning areas in spring and subsequently dispersed 5 to 350 km to upstream home river locations where they remained for the rest of the year. During the spawning period, terrace and bluff pools, which are unique geomorphic units associated with bedrock and boulder substrate, were positively selected while all other habitat types were avoided. Tributary use during spawning was rare. Following movement to home river locations, sauger used most habitat types in proportion to their availability but selected reaches of specific geologic types. Exploitation occurred primarily in early spring and late autumn. Annual survival was high (70.4%). Entrainment in irrigation diversions may have accounted for more than half of non-fishing mortality. Migratory barriers, habitat loss, and overexploitation of adult sauger likely are not preventing sauger recovery, but the effects of these factors may be more pronounced for juvenile sauger. Habitat alteration and interactions with non-native walleye and smallmouth bass may also preclude recovery.

INTRODUCTION

Sauger were historically present in the Yellowstone River and its tributaries from its confluence with the Missouri River upstream to the coldwater-to-warmwater fish-assemblage transition zone near Big Timber, Montana (Brown 1971; Haddix and Estes 1976; Holton and Johnson 1996). Over the past 100 years, sauger distribution in the Yellowstone watershed has decreased as a result of habitat loss, fragmentation, and alteration, primarily related to the installation of hydroelectric and low-head irrigation diversion dams on tributaries (McMahon 1999). Distribution in tributaries has decreased by 95%; sauger are considered rare or absent in the Tongue and Big Horn rivers in Montana, but still occur in the Powder River (McMahon and Gardner 2001). The mainstem distribution of sauger was thought to extend from near Cartersville Diversion downstream to the Missouri River, a loss of nearly one third of the historical range (McMahon and Gardner 2001).

Fluctuations in sauger abundances from 1987 to 1999, combined with reduced distribution, heightened concern over the status of the fishery. Sauger year class strength in the Yellowstone River appeared to be partially related to hydrologic factors; a positive correlation existed between year class strength and spring-summer discharge in the Yellowstone River and water levels in Lake Sakakawea (Stewart 1996; McMahon and Gardner 2001). Abundances above Intake Diversion declined to historical lows following region-wide drought from 1987 through 1990 (McMahon and Gardner 2001). However, failure of the sauger population to recover following five out of seven years of above-average spring-summer discharge from 1991 through 1997, suggested that factors other than simply discharge and reservoir levels affected abundances (McMahon and Gardner 2001). Declines in the Yellowstone watershed, as well as a synchronous decrease in abundance and lack of subsequent recovery by other Montana sauger populations, led to the classification of sauger as an imperiled Species of Special Concern in Montana in 2001 (Carlson 2003). Migratory barriers, habitat loss, overexploitation, and entrainment at irrigation diversions were suggested to explain the failure of Yellowstone River sauger to return to historical abundances (McMahon and Gardner 2001). However, lack of information regarding sauger exploitation rates and ecology, specifically as they relate to seasonal movement patterns and habitat use, made it difficult to assess the validity of these hypotheses and effectively manage sauger in the Yellowstone River (McMahon and Gardner 2001).

Unrestricted access to widely separated and diverse habitat types throughout the year is critical to riverine fishes in general (Schlosser 1991; Fausch et al. 2002) and previous studies indicate seasonal differences in use of spatially distinct habitat types by sauger appear common (Hesse 1994; Gardner and Stewart 1987). Sauger spawning locations are associated with unique geomorphic features, such as bluff pools and bedrock reefs, and rocky substrates (Nelson 1968; Gardner and Stewart 1987; St. John 1990; Hesse 1994). Home locations are frequently associated with off-channel and channel-margin habitats during the spring and early summer periods of high flow and turbidity, and deeper main channel habitats in late summer and autumn (Gardner and Stewart 1987; Hesse 1994). Lengthy migrations between spawning and home locations are common (Nelson 1968; Collette et al. 1977; Penkal 1992; Pegg et al. 1997). Six mainstem low-head irrigation diversion dams on the Yellowstone River were suspected to individually or cumulatively restrict sauger movement (Graham et al. 1979; Swedberg 1985; Helfrich et al. 1999) thereby impeding recovery by limiting access to seasonally important habitats (McMahon 1999). The effects of diversion dams on sauger recovery in the Yellowstone River were unknown because seasonal patterns of movement and habitat use, especially during summer and winter months, were poorly described (McMahon and Gardner 2001).

The apparent failure of sauger stocks to recover was also inferred to be related to the loss of critical spawning habitats in the Yellowstone watershed. The Yellowstone River sauger population appeared to be supported by limited spawning habitat; the only documented spawning areas in the Yellowstone watershed since the mid-1970s were the Tongue and Powder rivers and a short mainstem section immediately below Intake Diversion (Penkal 1992). These habitats were also used by sauger from the Missouri River and Lake Sakakawea suggesting a scarcity of suitable spawning habitats over a relatively large area (Penkal 1992; McMahon 1999). However, sufficient flows for sauger to spawn (15 m^3/s; Elser et al. 1977) did not occur in the Tongue River in 19 of the 24 years from 1980 to 2003 because of dewatering for irrigation. Whether additional spawning areas existed or had been colonized in the Yellowstone watershed following loss of the Tongue River was unknown.

Excessive exploitation was suggested to contribute to the failure of the Yellowstone River sauger fishery to rebound. Sauger are highly susceptible to overexploitation because of the apparent seasonal aggregations of entire stocks in discrete spawning areas (St. John 1990; Penkal 1992) and a migratory behavior that may result in unusually high concentrations of sauger at dams and diversion structures (Nelson 1969; Hesse 1994; Pegg et al. 1996). Overexploitation during periods of aggregation has been implicated in the collapse of several sauger fisheries (Hesse 1994; Pegg et al. 1996, Maceina et al. 1998). Anglers on the Yellowstone River are believed to seasonally target potential areas of aggregation and have become more sophisticated and efficient at harvesting sauger in recent years (Stewart 1992; McMahon 1999). However, exploitation was estimated to be less than 5% (Penkal 1992; Stewart 1998) but failure to incorporate tag loss and angler non-reporting rates may have resulted in underestimates of exploitation (McMahon 1999). For example, Tennessee River sauger were thought to experience exploitation rates of less than 10%, but inclusion of tag loss and non-reporting rates in analysis indicated that exploitation rates ranged from 28 to 89% (Maceina et al. 1998). Exploitation rates on the Yellowstone River may have been as high as 40% if adjusted for typical non-reporting levels (McMahon 1999). Adjusting rates to account for tag loss could further increase these estimates (Pegg et al. 1996).

Sauger recovery was also hypothesized to be prevented by entrainment in irrigation canals associated with diversions. An average of 67,137 sauger were entrained from June through September each year in the Intake Canal from 1996 through 1998 (Hiebert et al. 2000). The majority of the entrained sauger were 2 to 3 years old (250-375 mm) but sauger age 0 to age 8 (42-544 mm) were entrained based on length-age relationships for Yellowstone river sauger (Haddix and Estes 1976; Penkal 1992; Hiebert et al. 2000). A negative correlation exists between the number of sauger entrained and

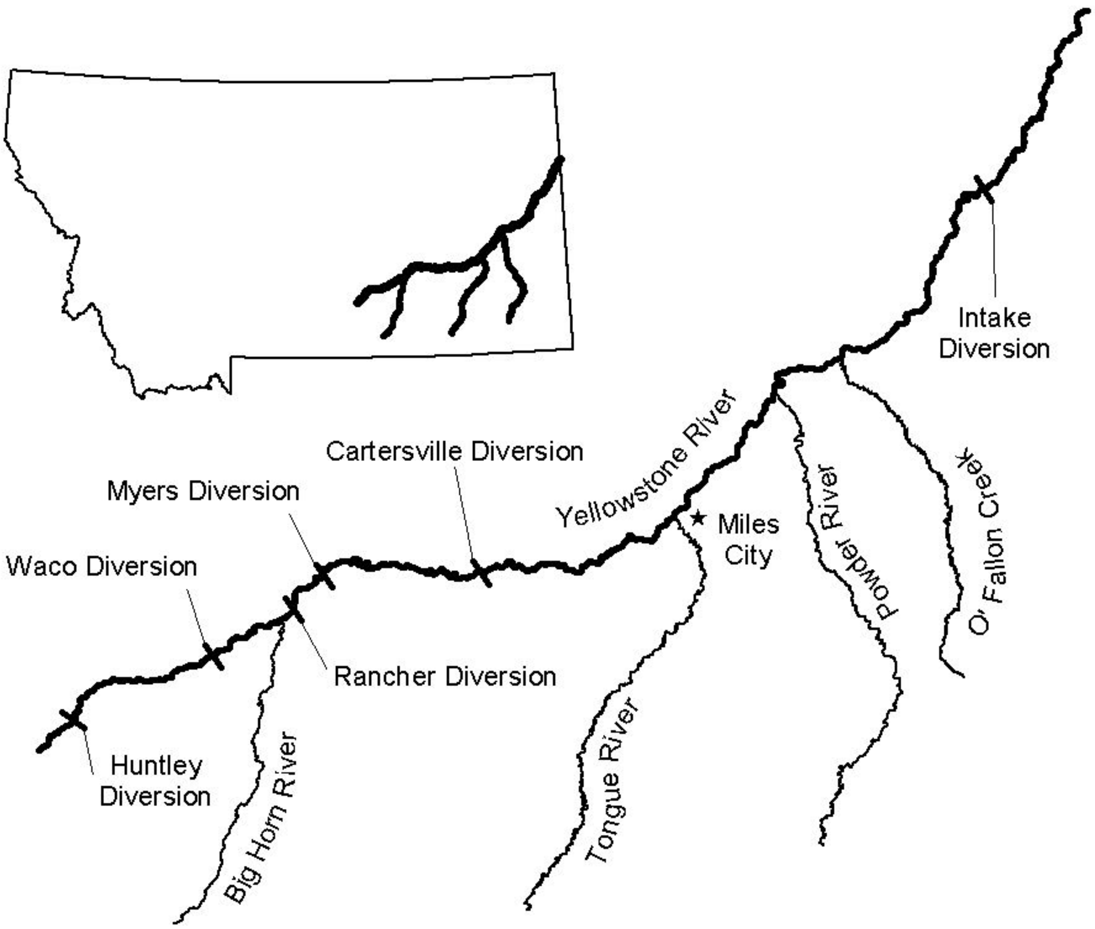
Yellowstone River discharge (Hiebert et al. 2000) that may partially explain the observed positive relationship between spring-summer flows and year class strength (McMahon and Gardner 2001). Although the number of sauger entrained in Intake Canal was estimated, actual mortality rates related to entrainment were unknown making it difficult to gauge the effect of entrainment relative to other sources of mortality for the Yellowstone River sauger population.

My objectives were to characterize seasonal movement patterns, habitat use, and aggregation, and estimate movement, exploitation, and Intake Canal entrainment rates of the Yellowstone River adult sauger population. They were directed at determining which factors prevented recovery of the Yellowstone River sauger fishery. Assessment of movement patterns and rates provided an understanding of the extent that diversion dams restricted sauger movement throughout the year. Evaluation of habitat use allowed characterization of seasonally important habitat types and elucidated the role of diversion dams in preventing sauger from accessing them. Investigation of habitat use also allowed assessment of whether spawning habitat was limited. Description of seasonal patterns of aggregation provided an understanding of times and locations that sauger were most susceptible to overexploitation. Estimation of exploitation rates incorporating tag loss and angler non-reporting allowed accurate assessment of angler harvest. Estimation of entrainment rates in Intake Canal provided a better understanding of the effect of entrainment at irrigation diversions relative to other sources of mortality. Satisfying these objectives provided information to guide the formulation of management strategies to benefit the recovery of the Yellowstone River sauger fishery.

STUDY AREA

The study area consisted of the lower 563 km of the Yellowstone River from near the Huntley Diversion, Montana, downstream to the confluence with the Missouri River, North Dakota (Figure 1). The Yellowstone River is the longest free-flowing river in the contiguous United States and the study area represents some of the most pristine large-river habitat in North America (White and Bramblett 1993). Mean annual discharge at the USGS gauging station in Miles City, Montana, is 323 m^3/s and mean annual peak discharge is 1480 m^3/s. River geomorphology varies throughout the study area in direct response to valley geology; straight, sinuous, braided, and irregular-meander channel patterns occur (Silverman and Tomlinsen 1984). The channel is often braided or split and long side channels are common. Islands and bars range from large vegetated islands to unvegetated point and mid-channel bars (White and Bramblett 1993). Substrate is primarily gravel and cobble upstream of river kilometer 50 and is primarily fines and sand below (Bramblett and White 2001). The fish assemblage is comprised of 49 species from 15 families, including eight state-listed Species of Special Concern and one federally listed endangered species (White and Bramblett 1993; Carlson 2003). The primary deleterious anthropogenic effect on the fish assemblage is water withdrawal for agriculture (White and Bramblett 1993). About 90% of all water use on the Yellowstone River is for irrigation, which corresponds to annual use of 1.5 million acre-feet (White and Bramblett 1993). Six mainstem low-head irrigation diversions dams occur in the study area (Figure 1). The largest and downstream-most of these, Intake Diversion, diverts about 38 m^3/s during the mid-May to mid-September irrigation season (Hiebert et al. 2000).

Figure 1. The lower Yellowstone River, its major tributaries, and diversion dams.



METHODS

Thirty or thirty-one sauger weighing 300 to 2350 g were collected by electrofishing or hook-and-line sampling each April from 2001 to 2003 in the Yellowstone River between Cartersville Diversion (river km 379) and O'Fallon Creek (river km 204), which enters the Yellowstone River about 30 km downstream of the Powder River (Figure 1). Efforts were concentrated here because declines in abundances were most marked in this reach and sauger were no longer thought to occur above Cartersville Diversion (McMahon and Gardner 2001). About 2 out of every 15 kilometers were sampled to minimize bias related to tagging location and obtain a representative sample. In 2003 sauger were only collected directly downstream of the Powder and Tongue rivers to assess tributary use. Only adult sauger were used as determined by the expression of gametes or lengths greater than 350 mm (Haddix and Estes 1976; Carlander 1997). Radio transmitters were implanted immediately following capture to minimize stress related to holding fish in captivity. I used transmitters of two sizes to maximize battery life while avoiding transmitter to body weight ratios in excess of 2% (Winter 1996). Small transmitters were 50 mm long and 10 mm in diameter, weighed 8.2 g, and had a minimum battery life of 300 days. Large transmitters were 50 mm long and 16 mm in diameter, weighed 14.3 g, and had a minimum battery life of 730 days. I used twenty-four small transmitters and six large transmitters in 2001, twenty small transmitters and eleven large transmitters in 2002, and only small transmitters in 2003. Radio transmitter frequencies ranged from 48.012 to 48.991 MHz and each transmitter was equipped with a mortality sensor. Transmitters were implanted using procedures modified from Hart and Summerfelt (1975). Incisions were closed using size 35W stainless steel surgical staples (Pegg et al. 1997) and 300-mm long whip antennae trailed externally (Ross and Kleiner 1982). Transmitters were labeled with my return address and phone number to facilitate return by the public if fish were harvested or found dead. Following surgery, sauger were placed briefly in a holding tank until they recovered from anesthesia and released near the point of capture.

Sauger telemetered in 2001 and 2002 were relocated by boat once per week from April through June and twice per month from July through October. During November through March, when the river was ice-covered, relocations were made by aircraft once during the winter of 2001 to 2002 and twice during the winter of 2002 to 2003. Sauger telemetered in 2003 were relocated weekly from April through June by boat or judged to have moved into the Powder or Tongue rivers if recorded by permanent receiving stations near the mouths of these tributaries. The permanent receiving stations were deployed only in 2003.

Following detection, each sauger was located by triangulation and coordinates of the location were determined using a hand-held global positioning unit (Winter 1996). Location was converted to river kilometer using geographic information system (GIS) software.

Movement

Annual patterns of movement between spawning and home locations were described with plots of individual and combined relocation histories of sauger telemetered throughout the study. Associations of movements with discharge and predicted stream temperature were described graphically. Discharge data were obtained from the Miles City, Montana, USGS gauging station. Average daily stream temperature in Miles City was modeled from April 2001 to June 2003 using a linear regression model and stream temperature data collected continuously from the Yellowstone River at Miles City from March 21 to September 30, 2003 (Stefan and Preud'homme 1993). Stream temperature was predicted ($P < 0.001$, $r^2 = 0.937$) using average daily air temperature at Miles City and average daily Yellowstone River stream temperature at Livingston, Montana (Stefan and Preud'homme 1993; Mohseni and Stefan 1999).

Total and net movement rates (km/d) during each month were calculated for each telemetered sauger. Total movement rate was calculated by dividing the distance in river kilometers between successive relocations for a given fish by the number of days that had elapsed between relocations (White and Garrott 1990). Net movement rate was calculated by dividing the change in river kilometer between successive relocations by the number of days that had elapsed between relocations such that a positive rate indicated upstream movement and a negative rate indicated downstream movement (Bramblett 1996). Because additional movement may have occurred between relocations, calculated movement rates represent the minimum movement for the time period between relocations. Median monthly movement rates were compared using a Kruskal-Wallis test (Zar 1999). When significant differences were detected, Dunn's multiple comparisons test was used to determine which monthly rates differed (Zar 1999).

Habitat Use

Seasonal habitat selection was examined at two hierarchically nested spatial scales: segment-scale reaches classified based on underlying geologic type and pool/riffle-scale habitat types (Frissell et al. 1986). Geologic types were delineated using geologic maps (Montana Bureau of Mines and Geology 1979-2001b) and GIS software. To ensure that geomorphic changes were observable and that a hierarchical spatial framework was maintained, geologic type reaches were required to exist continuously for a minimum of 20 channel widths (about 4 km) to be considered a separate reach (Frissell et al. 1986; Leopold et al. 1992). Geologic types were delineated from river kilometers 74 to 537, the range that represented the total observed distribution of telemetered sauger.

Habitat types were delineated using low-level 1:24,000 scale color infrared aerial photographs (Natural Resources Conservation Service 2002), geologic maps (Montana Bureau of Mines and Geology 1979-2001b), and GIS software. Habitat types were classified as scour pool, bluff pool, terrace pool, valley bottom rip-rap scour pool, valley margin rip-rap scour pool, channel crossover, perennial secondary channel or seasonal secondary channel. Scour pools were habitat types created by scour through valley bottom alluvium (Montana Bureau of Mines and Geology 1979-2001b; Rabeni and Jacobson 1993). Bluff pools were created by scour against bedrock geology at the valley margin (Montana Bureau of Mines and Geology 1979-2001b; Rabeni and Jacobson 1993). Terrace pools were created by scour against alluvial terrace deposits and colluvium (Montana Bureau of Mines and Geology 1979-2001b). Valley bottom and valley margin rip-rap scour pools were created by scour against rip-rap bank stabilization structures occurring in the valley bottom or at the valley margin, respectively (Natural Resources Conservation Service 2002). Channel crossovers occurred where the thalweg moved from one side of the channel to the other as indicated by the presence of alternating depositional point bars (Natural Resources Conservation Service 2002). Perennial secondary channels were secondary channels that were clearly connected to the main channel at both ends and continuously held water throughout their length at base flow (Natural Resources Conservation Service 2002). Seasonal secondary channels were not clearly connected to the main channel at both ends or did not continuously hold water throughout their length at base flow, but were likely fully connected during runoff (Natural Resources Conservation Service 2002).

Total linear availability of each geologic and habitat type during base flow and runoff periods was quantified using GIS software. Quantification was performed in a hierarchical manner such that the availability of each habitat type within a given geologic type was determined to allow for comparisons of habitat type selection among geologic types. Availability at base flow was calculated by considering the amount of habitat provided by all habitat types except seasonal side channels. Availability during runoff included seasonal side channels.

Seasonal habitat use by sauger at both spatial scales was determined using all telemetry relocations. Seasons were based empirically on life history characteristics and movement rates of sauger. Seasons included spawning (March 15 to May 15), post-spawning movement (May 16 to July 31), autumn (August 1 to November 30), and winter (December 1 to March 14). Spawning was verified by examining the condition of adult sauger collected by electrofishing. Habitat use by individual sauger was calculated for each season as the proportion of relocations that were made within each geologic type, habitat type, and habitat type stratified by geologic type (Manly et al. 2002). Use at the geologic-type scale was determined using GPS coordinates of each relocation, geologic maps (Montana Bureau of Mines and Geology 1979-2001b), and GIS software. Use at the habitat type scale was determined using GPS coordinates of each relocation and notes regarding habitat type, channel position, and stream bank characteristics and landmarks at the point of relocation, as well as geologic maps (Montana Bureau of Mines and Geology 1979-2001b), color infrared aerial photographs (Natural Resources Conservation Service 2002), and GIS software.

Chi-square tests with log-likelihood test statistics (Manly et al. 2002) were used to test the null hypothesis of seasonal selection in proportion to availability for different geologic types, habitat types, or habitat types stratified by geologic type. Although some expected values were less than the commonly recommended minimum of 5 (Zar 1999), chi-square tests are robust to much smaller expected values (Roscoe and Byars 1971; Lawl and Upton 1984). If selection was established, selection ratios and simultaneous 95% Bonferroni confidence intervals (Manly et al. 2002) were used to determine level of selection for specific resource categories. Selection ratios for the population were obtained by averaging selection ratios calculated for individual telemetered sauger (Manly et al. 2002).

Aggregation

Spatial distribution was examined for each week of telemetry relocations using a one-dimensional adaptation of neighbor K statistics following the example of O'Driscoll (1998). Analysis was performed using Matlab® code provided by Richard O'Driscoll (R. O'Driscoll, National Institute of Water and Atmospheric Research, Kilbirnie, Wellington, New Zealand, personal communication). The results of this analysis were presented as plots of L(t) as a function of t, where L(t) is the average number of neighbors above those that would be expected within distance t of any given individual if fish were distributed randomly. Statistical significance of spatial pattern was determined by including 90% confidence intervals of L(t) obtained from 999 randomizations, which represent the significance level of P = 0.10. At distance scale t, individuals were considered to be aggregated when L(t) was greater than the upper 90% confidence interval, randomly distributed when L(t) fell between the upper and lower 90% confidence intervals, and regularly distributed when L(t) was less than the lower 90% confidence interval. Edge bias was not corrected for because the distribution and range of sauger in the sample were assumed to be representative of the complete distribution and range of the target population.

The first peak in L(t) represented the characteristic spatial scale of clustering, or patch length. Patch length was defined as the first distance t at which a maximal significant difference existed between the observed number of neighbors and the number of neighbors expected if fish were randomly distributed. The height of the first peak in the plot of L(t) represented a measure of the intensity of distribution, or degree of crowding. Crowding was defined as the difference between the observed and expected number of neighbors at the scale of the patch length and provides a measure of the number of individuals that are grouped together in a patch. Patch length and intensity of spatial pattern was plotted continuously over the study period using an unpublished index of clustering developed by Richard O'Driscoll. The index is calculated by dividing the average number of individuals within distance *t* of any given individual in the distribution of telemetered sauger by the average number of individuals within distance *t* of any given individual in the distribution for the simulations at each distance *t*.

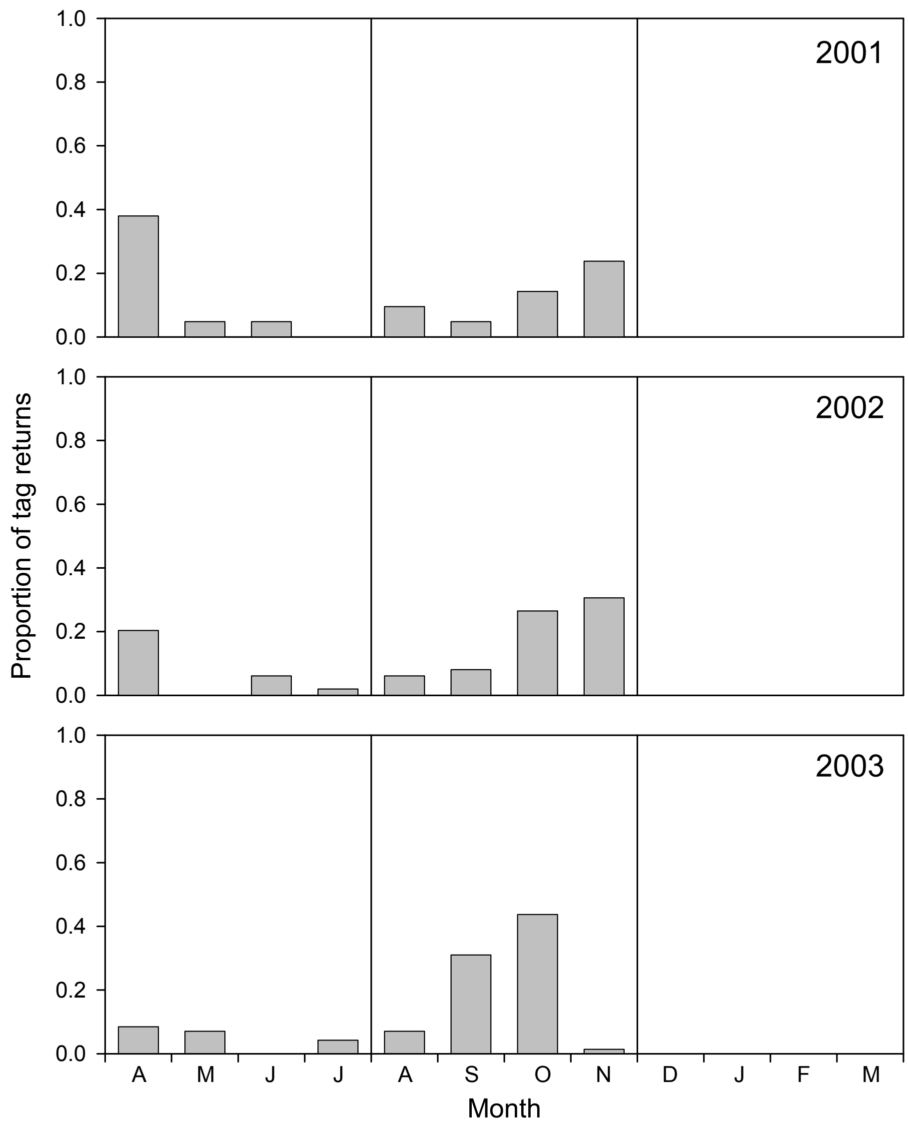
Exploitation

Exploitation was examined by assessment of tagged fish recaptured by anglers. A total of 199 sauger in 2001, 332 sauger in 2002, and 295 sauger in 2003 were tagged between Cartersville Diversion (river km 379) and Intake diversion (river km 71). Sauger were captured by electrofishing or hook and line sampling. Each sauger received two individually numbered Floy FD-94 T-bar tags inserted below the spiny and soft dorsal fins about 1 cm apart. Tags were marked "REWARD" and included a telephone number to report recovery of tagged fish. Tagged sauger were released near their point of capture. Tagging occurred during the spawning and autumn seasons; 62 to 84% of the tagging in a given year occurred during the spawning season. To minimize bias related to the lengthy tagging season, I maintained a similar median week of tagging during each year of the study (Smith et al. 2000). The median week of tagging was defined as the week at which 50% of the tags were released (Smith et al. 2000). To determine if the tagging regime resulted in biased estimates of annual survival or exploitation, a simulation program was designed to generate data sets from a virtual population subjected to similar monthly rates of tagging and natural and fishing mortality as those experienced by the lower Yellowstone River sauger population. Bias was assessed by estimating survival and exploitation for 100 generated data sets with the methods used to estimate these parameters for the study population.

Angler return of tagged fish was solicited by placing signs describing the project and providing postage-paid envelopes with attached tag-return forms at fishing-access sites along the Yellowstone River. Newspaper and radio advertisements and press releases describing the project and procedures to return tag recovery information were disseminated. Reward caps were mailed to anglers returning tags to attempt to enhance tag-return rates. Anglers were asked to provide their name, address, and phone number and the following information for each tagged sauger recovered: date and location the fish was caught or found, length and weight of the fish, whether the fish was kept or released, the number of tags recovered, and tag numbers. Anglers were able to return tags by mail, phone, or in person at the Montana Department of Fish, Wildlife, and Parks regional offices in Miles City and Billings.

Annual survival and annual and seasonal probabilities of capture and exploitation were estimated by analysis of T-bar tag returns with recovery models described by Brownie et al. (1985). Seasons were defined as spawning-movement (April 1 through July 31), autumn (August 1-November 30), and winter (December 1-March 31) based on distribution of fishing effort throughout the year (Figure 2) and patterns of sauger aggregation. Seasonal survival could not be calculated using T-bar tag returns because no detectable fishing occurred during winter.

Figure 2. Distribution of fishing effort as determined by proportion of T-bar tags returned from sauger in the Yellowstone River 2001 to 2003.



Candidate models allowing survival, probability of capture, and probability of exploitation to remain constant or vary through time were constructed and parameterized using Program MARK (White and Burnham 1999; Cooch and White 2001). Survival and probability of capture were estimated using tag returns of all captured fish during a given period. Exploitation was estimated only from tag returns of harvested fish. Goodness-of-fit testing was performed for each set of candidate models using the most general model and program ESTIMATE (Cooch and White 2001). The overdispersion parameter, c-hat, was calculated to assess lack of fit following Cooch and White (2001). If c-hat was greater than 1, models were appropriately adjusted to correct for overdispersion (Cooch and White 2001). Parameters and variance estimates were obtained by model averaging based on Akaike's information criterion values corrected for small sample (AIC_c) and, when applicable, overdispersion ($QAIC_c$) using Program MARK (Burnham and Anderson 1998; Cooch and White 2001). Survival estimates were adjusted for bias resulting from release of sauger following tag removal by anglers (Smith et al. 2000).

Tag returns from captured or harvested sauger were adjusted prior to analysis for tag loss and non-reporting. Tag loss was estimated by double tagging each sauger and using the tag-shedding model $Q(t) = (1\text{-}\rho)e^{(-Lt)}$, where $Q(t)$ is the probability of a tag being retained at time t after release, ρ is the immediate type-I shedding rate, and L is the continuous type-II shedding rate (Hampton 1997). Maximum likelihood estimates of ρ and daily L were obtained by minimizing the probability density function described by Hampton (1997). Tag returns were adjusted for tag loss each year or season by dividing the number of observed tag returns from a given period by 1 - $P_0(t)$, where $P_0(t)$ is the probability of no tags being retained at time t after release and $P_0(t) = [1\text{-}Q(t)]^2$ (Hampton 1997). The time interval t was the total length in days of the fishing period. Its use resulted in maximum estimates of tag loss because captured fish were not at large for the entire fishing year or season in which they were captured. Non-reporting of tagged fish was estimated using post cards as tag surrogates (Zale and Bain 1994). Non-reporting was adjusted for by multiplying the number of fish tagged during each fishing period by the reporting rate observed for the tag surrogates (Seber 1982).

Independent estimates of annual and seasonal survival rates were calculated using data from telemetered fish and known fate models parameterized in Program MARK (White and Burnham 1999; Cooch and White 2001). Telemetered sauger were required to have been located alive at the end of the period of interest to be considered to have survived that period. Sauger whose transmitters were emitting a mortality signal, were reported as harvested, or were not located following a given season were considered to have died during the period of interest. Possible fates other than mortality include emigration from the study area or transmitter failure (Seber 1982). Prior to estimation, encounter histories were adjusted for transmitter failure. Rate of transmitter failure is reported to be 10% over the lifetime of the transmitter (Dick Richle, Advanced Telemetry Systems, Isanti, Minnesota, personal communication); as a result, one fish per season or three fish per year that were not located were not counted as mortalities. Although I was not able to obtain emigration estimates, I searched well beyond the boundaries of the observed spatial distribution of telemetered sauger and therefore suspect emigration was low. However, because a possibility exists that sauger not relocated may have emigrated from the study area and survived, the estimates obtained should be considered to represent "apparent survival" and may be equal to or less than true survival. Parameter estimates and 95% confidence intervals were obtained using model averaging and AICc weights of candidate models using Program MARK (Burnham and Anderson 1998; Cooch and White 2001).

Entrainment

The number of sauger tagged in the Yellowstone River and entrained in Intake canal was estimated by dividing the number of sauger tagged in the Yellowstone River and captured by anglers in Intake canal by the exploitation rate of "canal resident" sauger. Canal residents were sauger that were tagged in Intake Canal following entrainment. Exploitation rate of canal resident sauger was estimated by tagging 71 sauger in 2001 and 60 sauger in 2002. Exploitation rate was calculated by dividing the number of canal resident sauger captured by anglers by the number of canal resident sauger tagged (Ricker 1975). Tag loss and non-reporting were adjusted for as described above. The annual probability of entrainment in Intake canal was calculated each year by dividing the estimated number of sauger tagged in the Yellowstone River and entrained in Intake canal by the number of sauger tagged in the Yellowstone River.

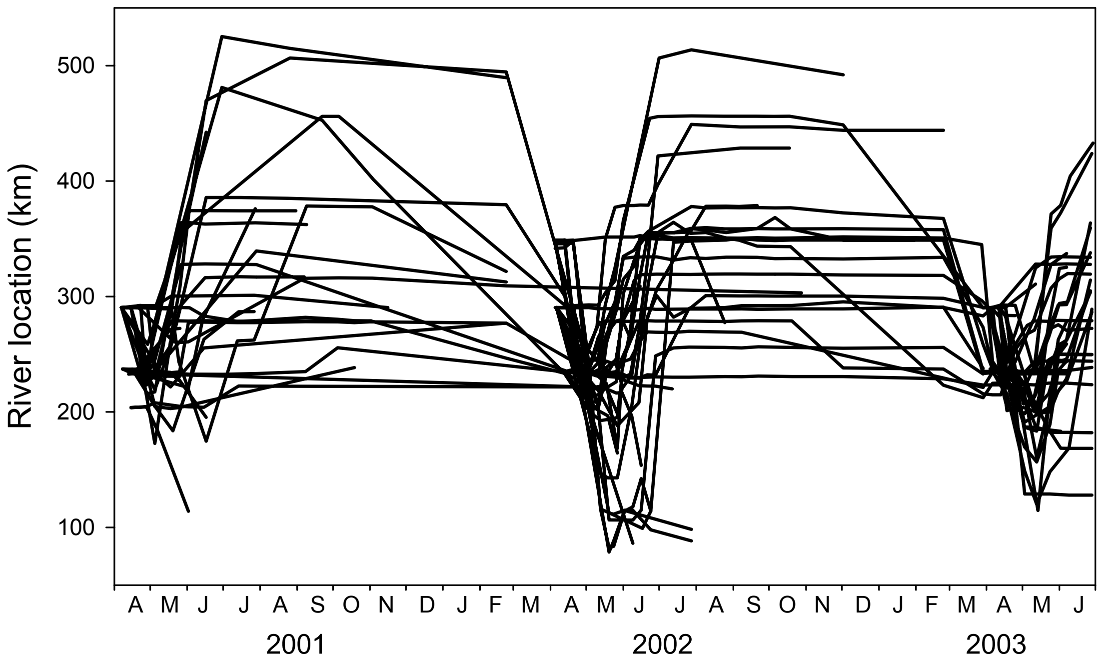
RESULTS

Movement

The observed annual movement pattern consisted of downstream movements to spawning areas in March through May followed by return movements to upstream home river locations in April through July (Figure 3). Home and spawning locations were spatially distinct (Figure 4). Initiation of upstream movement to home river locations occurred over a two-month period starting in mid-April. The periods of upstream movement were associated with annual peaks in river discharge and increasing stream temperatures (Figure 5). End of movement, or arrival at home river location, was highly variable and ranged from mid-May to early August. Initiation of downstream movement to spawning areas occurred in March and April following ice-out. The period of downstream movement was associated with increasing discharge related to lowland runoff and increasing stream temperatures (Figure 5).

Fish size influenced timing of spawning and post spawning migrations. Larger fish moved to home locations earlier (linear regression, $P < 0.001$; Figure 6). River kilometer (distance from the confluence with the Missouri River) of home location was positively correlated with fish length in 2001 ($P = 0.035$) and 2002 ($P = 0.004$; Figure 7). No relationship between movement rate or date of arrival at home location and fish length existed. Initiation date of upstream movement and arrival date at home location of sauger telemetered in 2003 was not examined because relocations were concluded before all fish began upstream movements or arrived at home location. Larger fish migrated downstream earlier; initiation of downstream movement to spawning areas was significantly negatively correlated with fish length ($P = 0.002$; Figure 8). Initiation date of downstream movement in 2002 could not be accurately determined because of sparse relocations during this period.

Figure 3. Movement pattern of telemetered sauger in the Yellowstone River, 2001 to 2003. Lines represent movements of individual telemetered sauger. River location describes the distance from the confluence with the Missouri River.



Total movement rates of sauger varied among months ($P < 0.001$; Figure 9), but were the same in specific months among years. Total movement rates were high from February through June (mean 1.00 km / day) and were not significantly different during these months within or among years. Net movement rates of sauger varied among months ($P < 0.001$; Figure 10), but were the same among years in specific months. In all years, net movement rates in June indicated predominately upstream movement and were significantly different than those in March through April, which indicated predominately downstream movement. Movements were nondirectional during all other months of the year.

Figure 4. Locations of spawning and home locations of telemetered sauger in the Yellowstone River, 2001 to 2003. Where overlap of data points occurs, spawning and home locations are displayed to insure that each distribution is accurately represented.

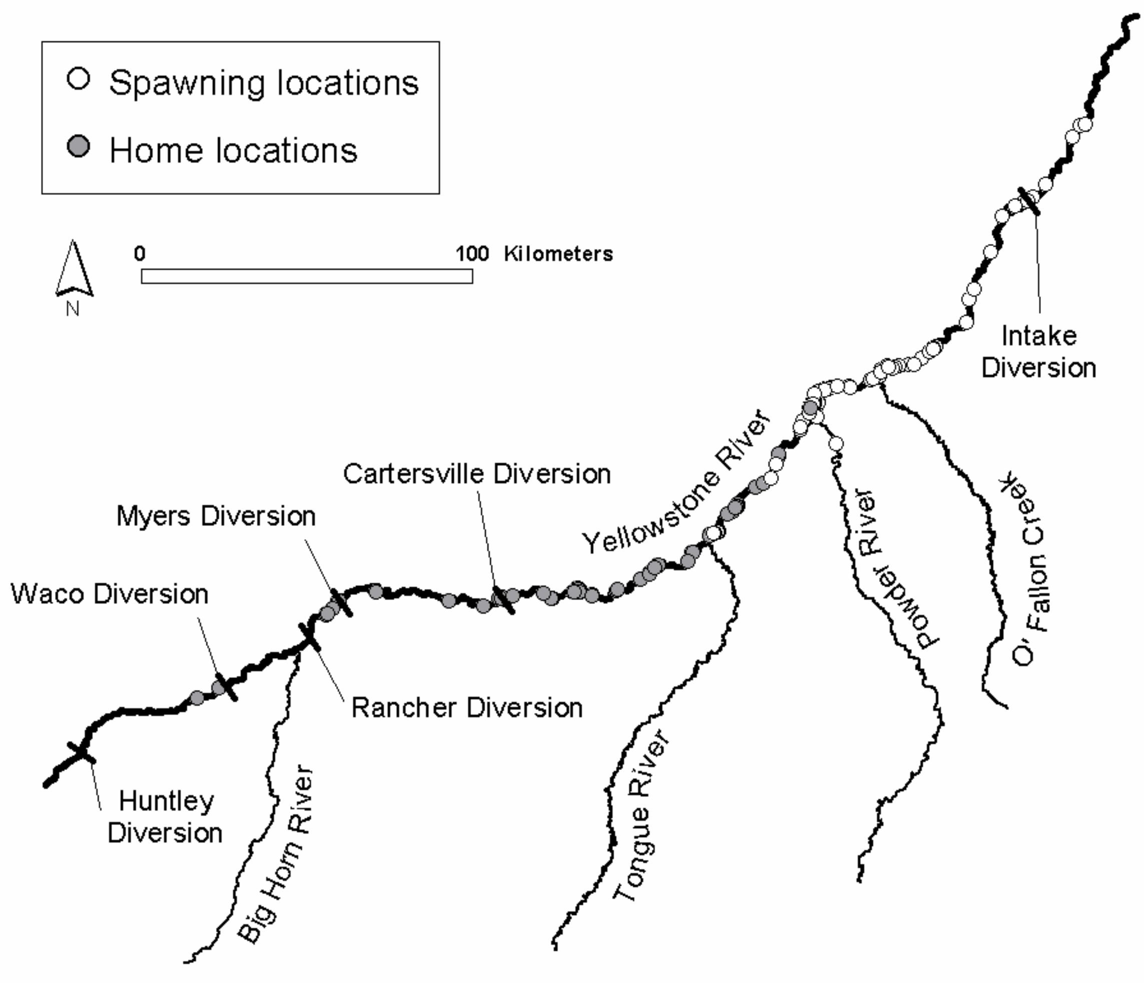
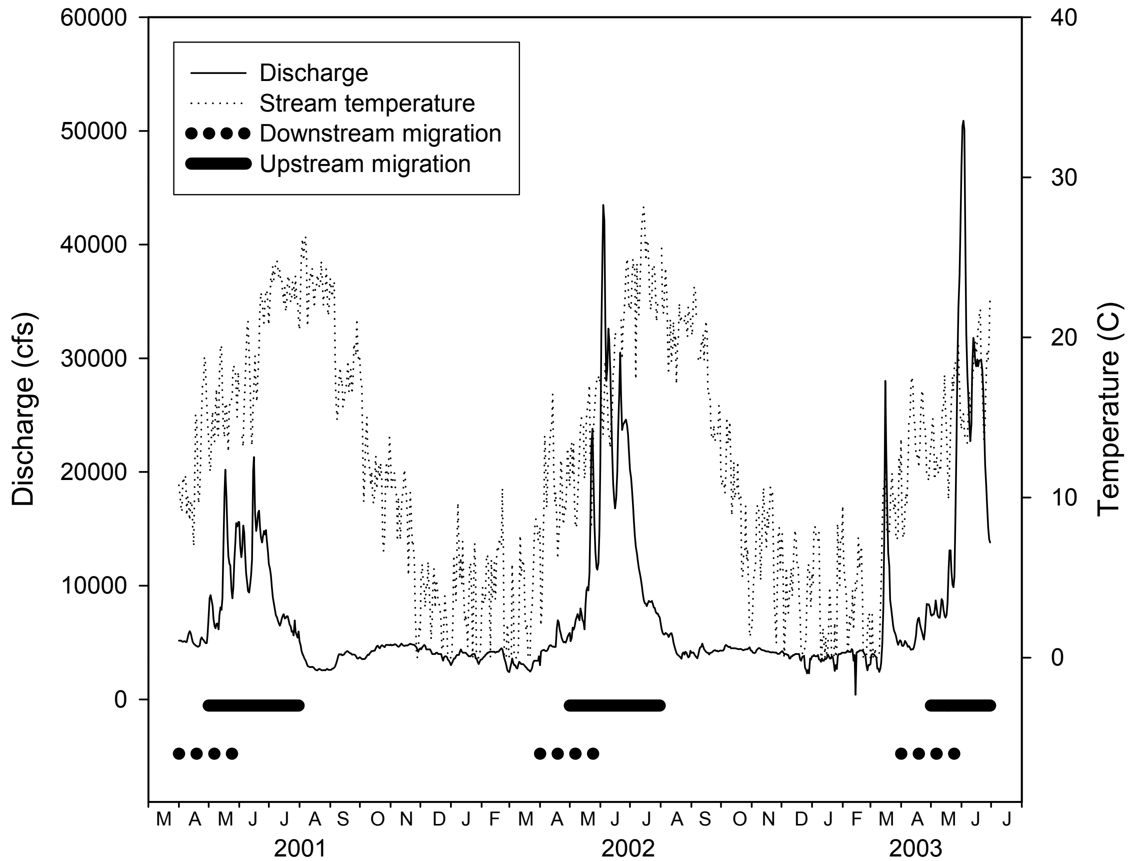


Figure 5. Association of movement periods of sauger with discharge and water temperature in the Yellowstone River.



Round-trip distance of annual migrations between spawning and home river locations ranged from 10 to 600 km and averaged 89.5 km (Figure 3). Average fidelity to spawning (4.7 km) and home river locations (1.2 km) was high for fish relocated over a complete migration cycle (Figure 11). Relocation histories for telemetered fish are displayed in Appendix A.

Figure 6. Relationship between sauger length and initiation date of upstream migration, Yellowstone River 2001 and 2002.

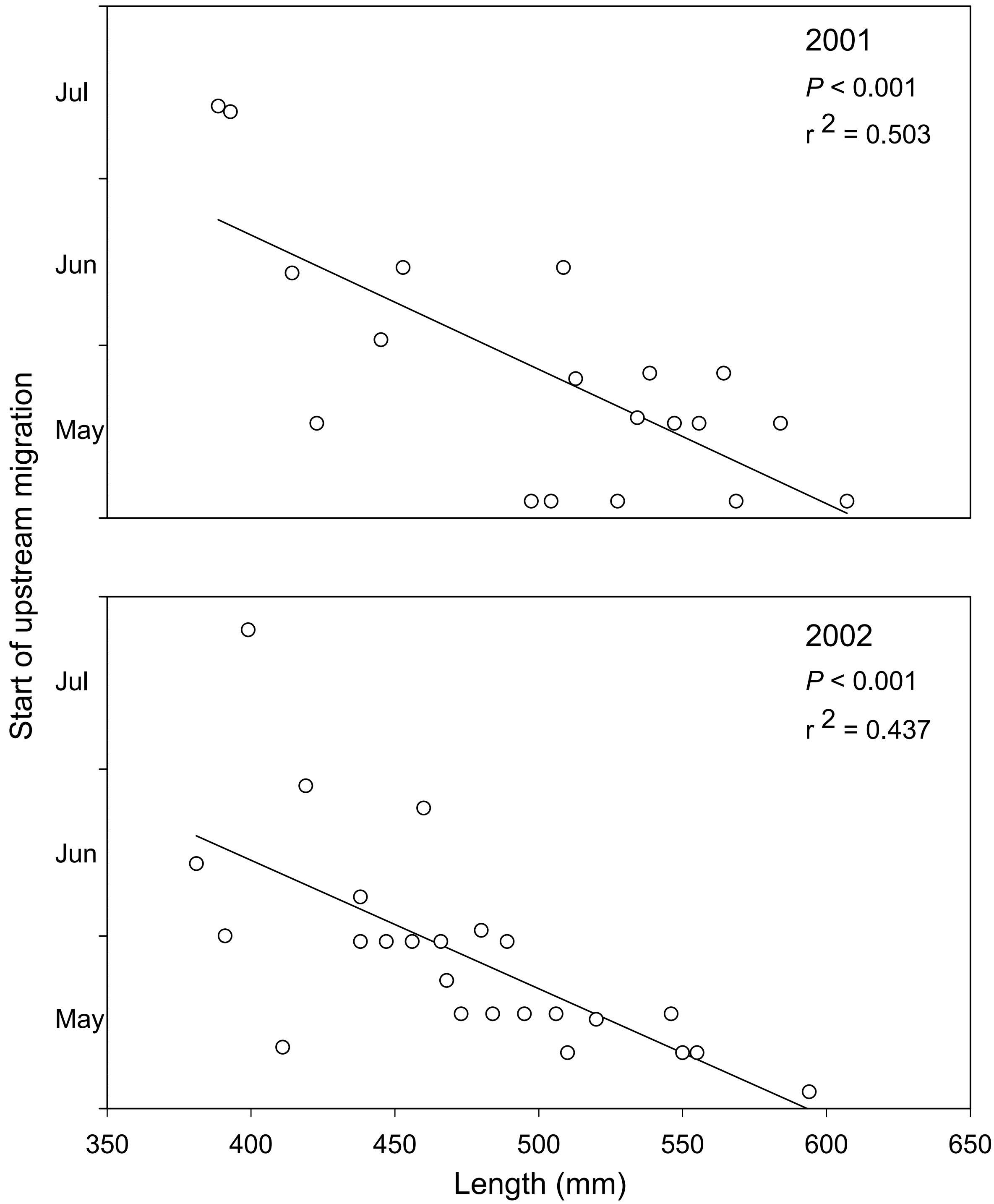


Figure 7. Relationship between sauger length and home river location, Yellowstone River, 2001 and 2002. River location describes the distance from the confluence with the Missouri River.

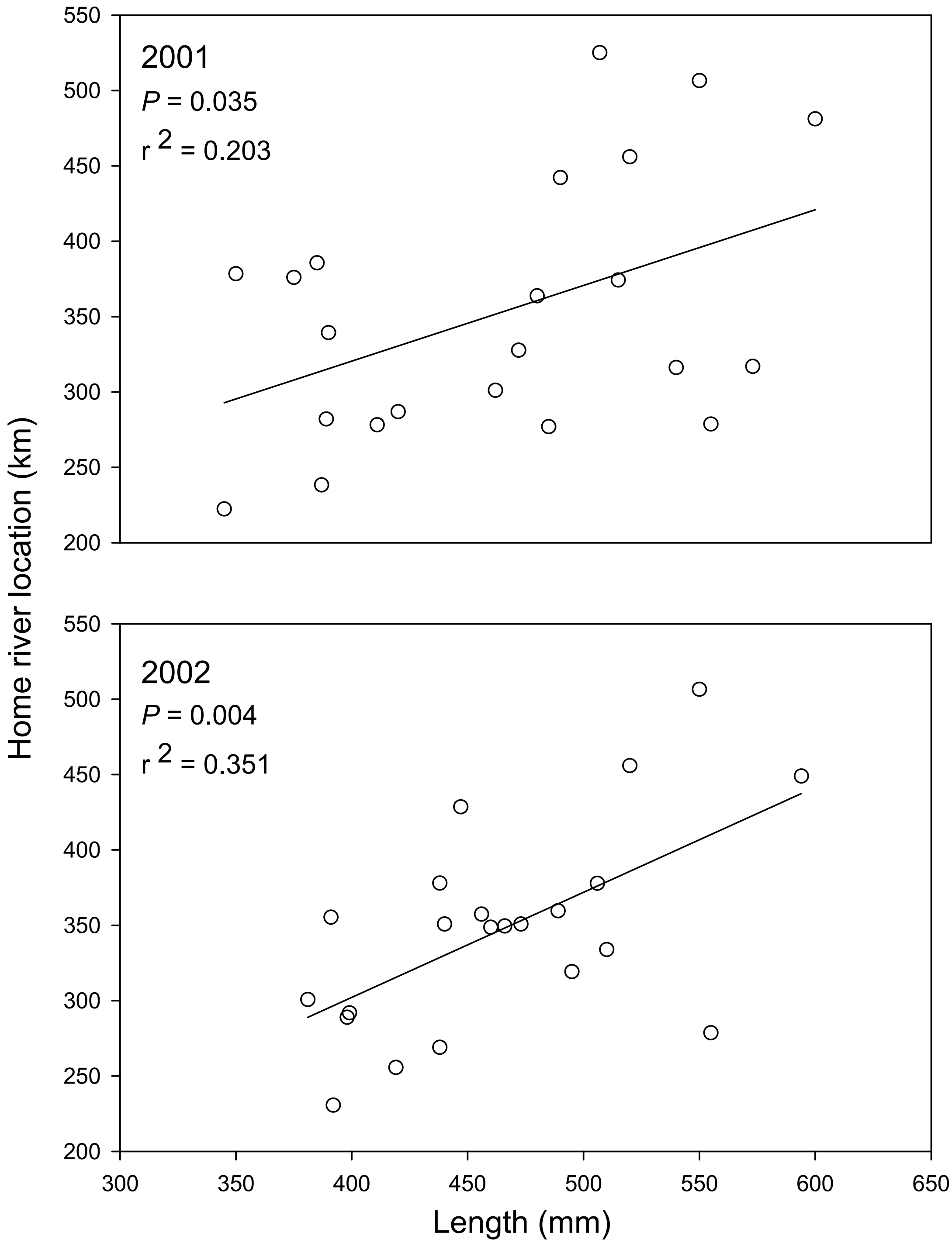


Figure 8. Relationship between sauger length and start date of downstream migration, Yellowstone River, 2003.

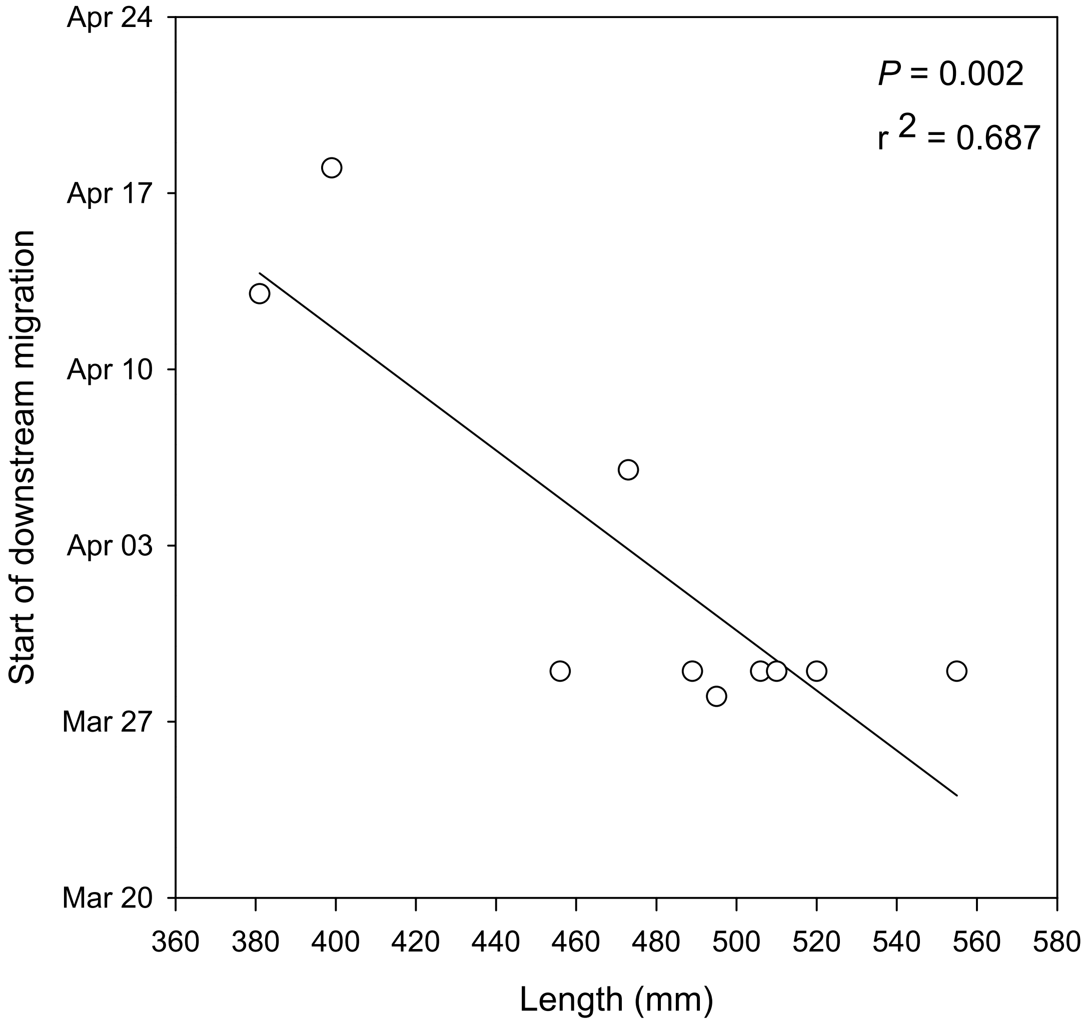


Figure 9. Total movement rates by month of telemetered sauger in the Yellowstone River, 2001 to 2003. Lines within boxes represent medians, boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and circles represent outliers beyond the 10th and 90th percentiles. Movement rates in months with the same letters are not significantly different among months or years ($P \leq 0.05$).

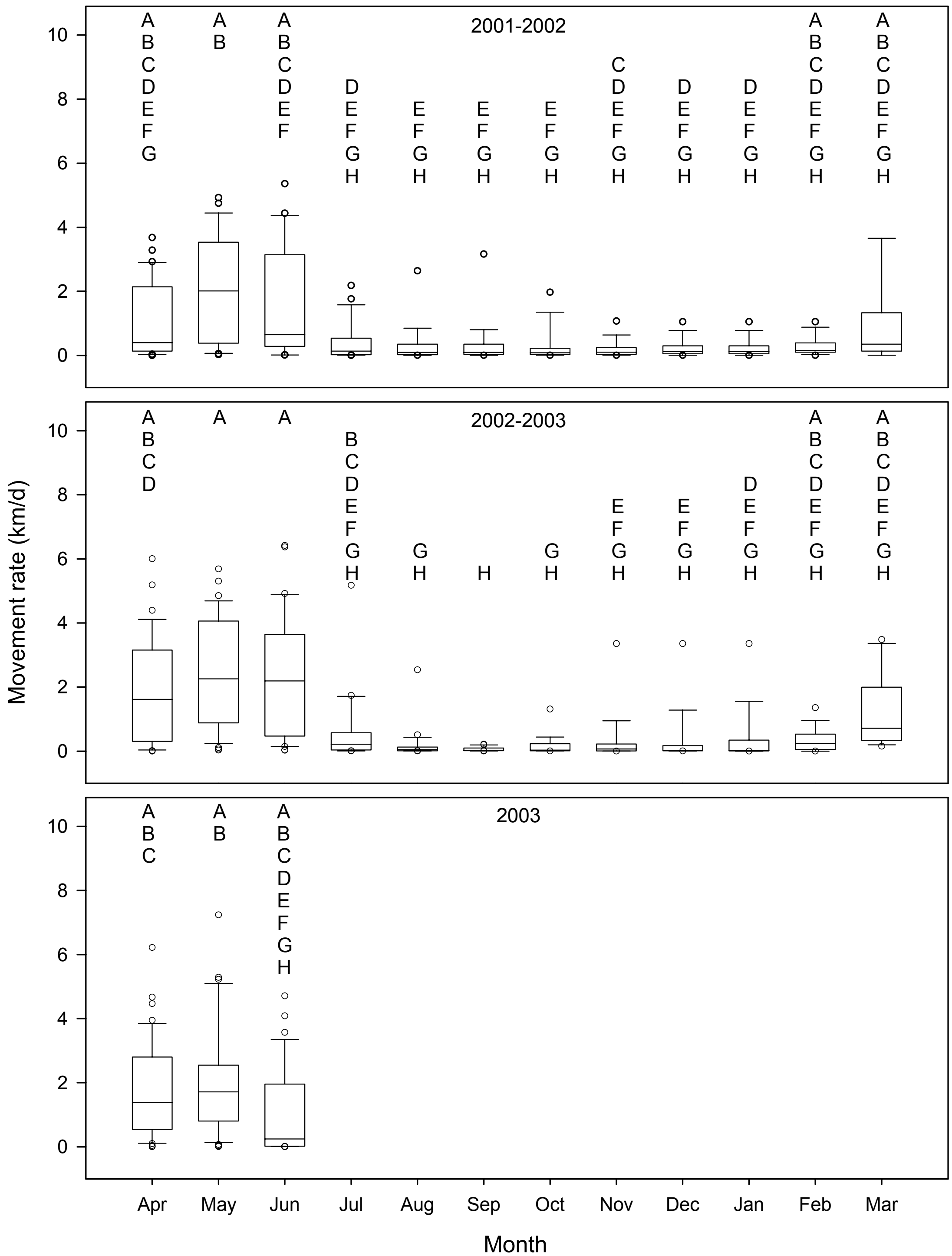


Figure 10. Net movement rates by month of telemetered sauger in the Yellowstone River, 2001 to 2003. Lines within boxes represent medians, boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and circles represent outliers beyond the 10th and 90th percentiles. Negative values indicate predominately downstream movement, positive values indicate predominately upstream movement, and values near zero indicate no predominate directionality of movement. Net movement rates in months with the same letters are not significantly different among months or years ($P \leq 0.05$).

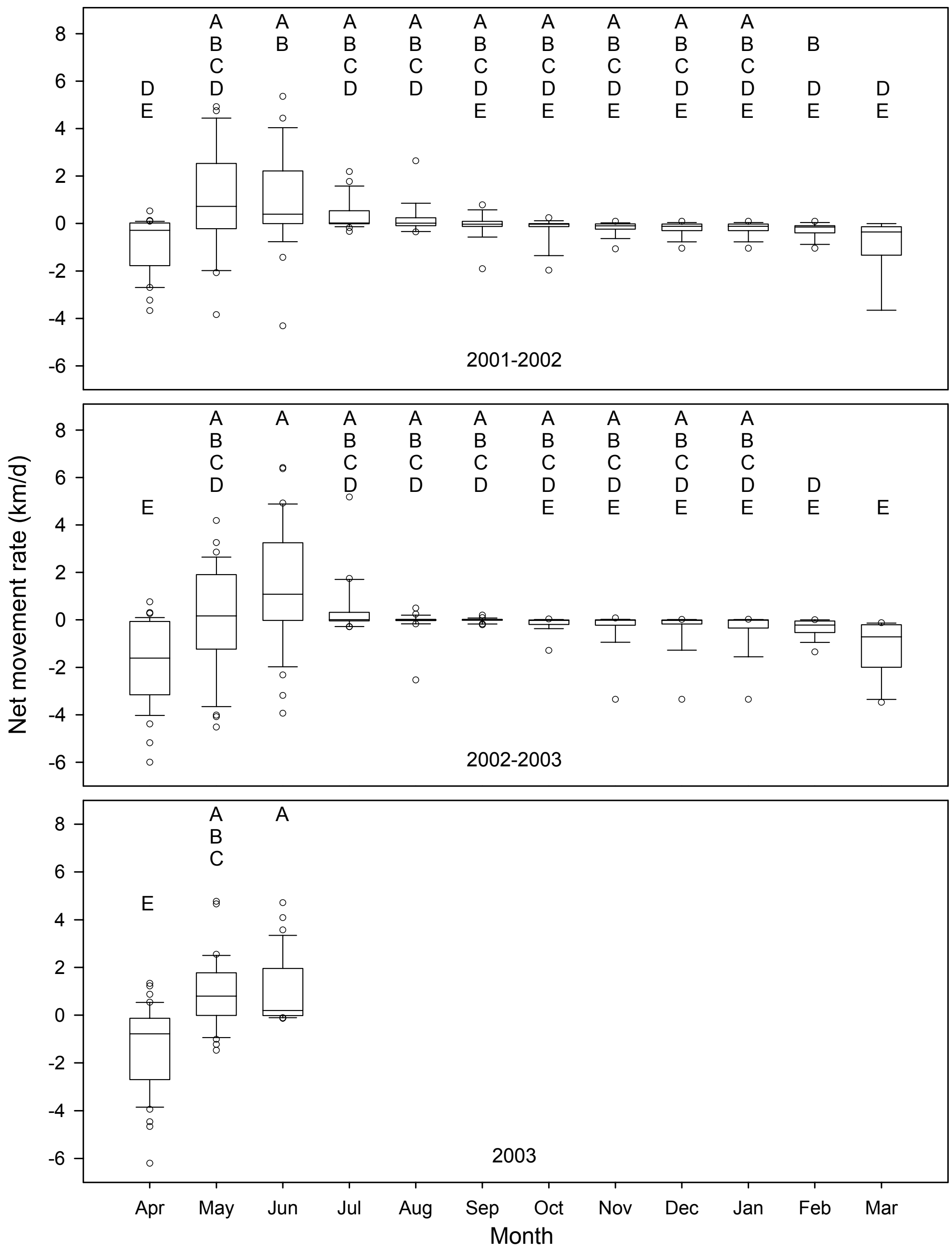
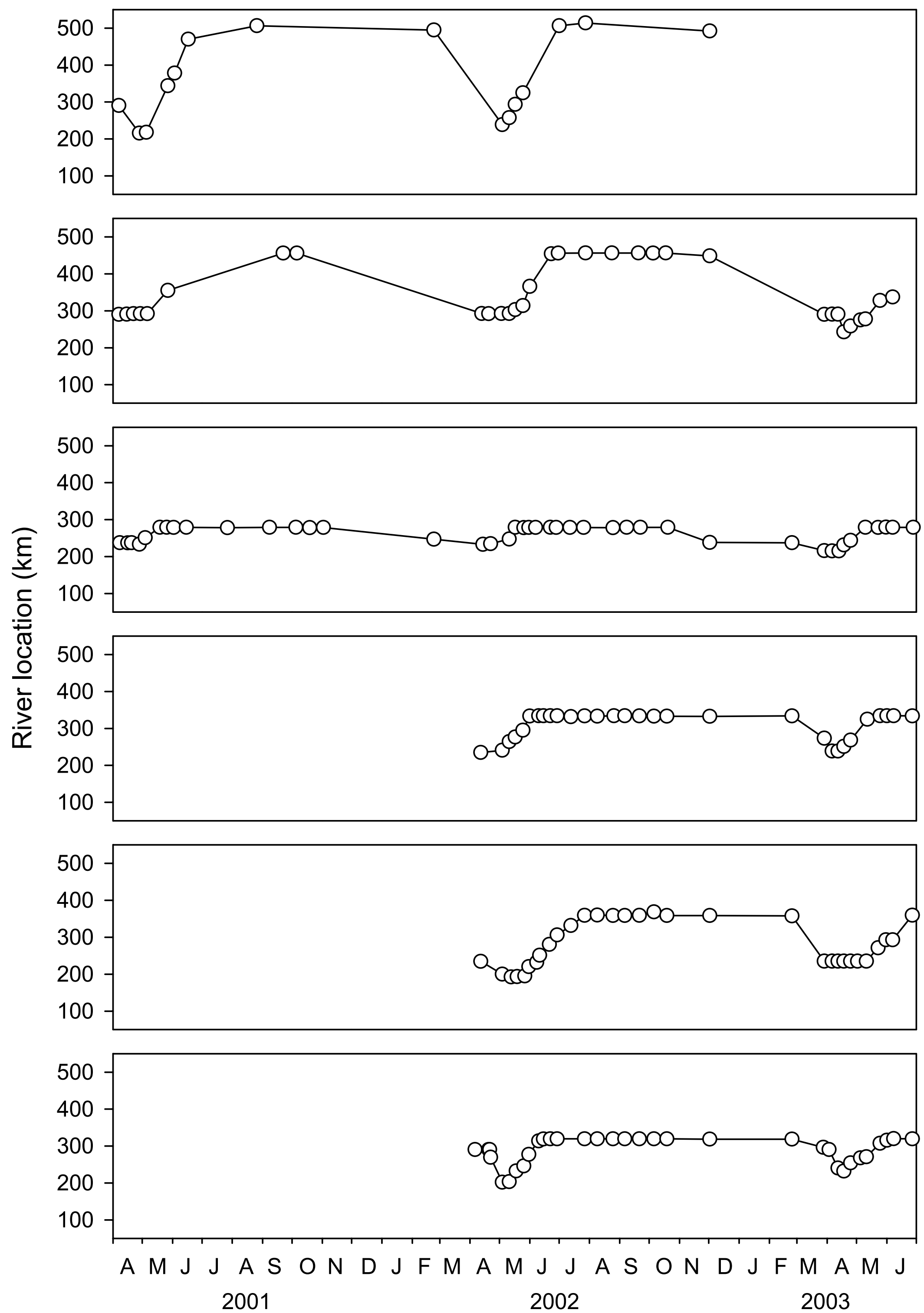


Figure 11. Encounter histories of individual telemetered sauger relocated over a period of greater than 14 months in the Yellowstone River, 2001 to 2003. River location describes the distance from the confluence with the Missouri River.



Habitat Use

Thirteen reaches of nine geologic types occurred in the study area (Figure 12). Sauger did not use resource categories in proportion to their availability except habitat types during the winter and habitat types nested within geologic types during the movement season (Table 1). Overall and nested seasonal availability and use of resource units are described in Appendix B.

Figure 12. Distribution of geologic types along the Yellowstone River, Montana.

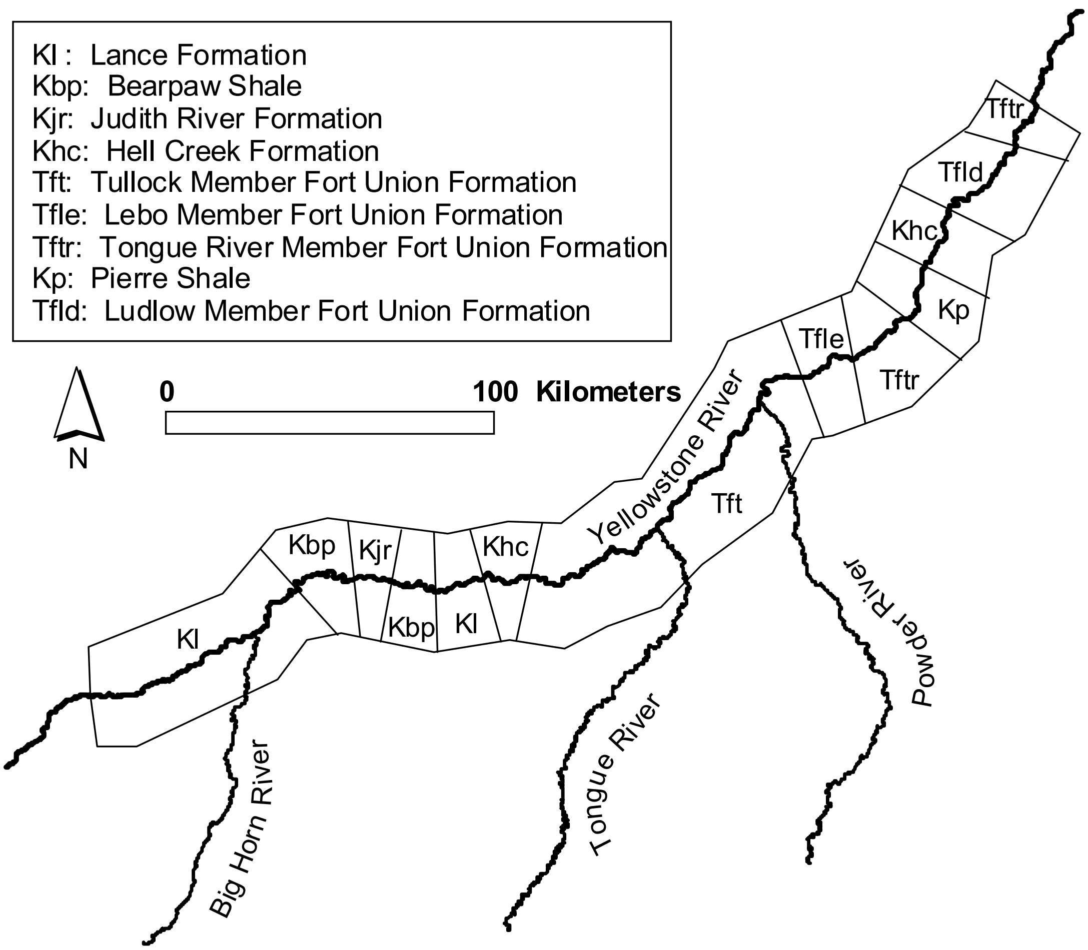
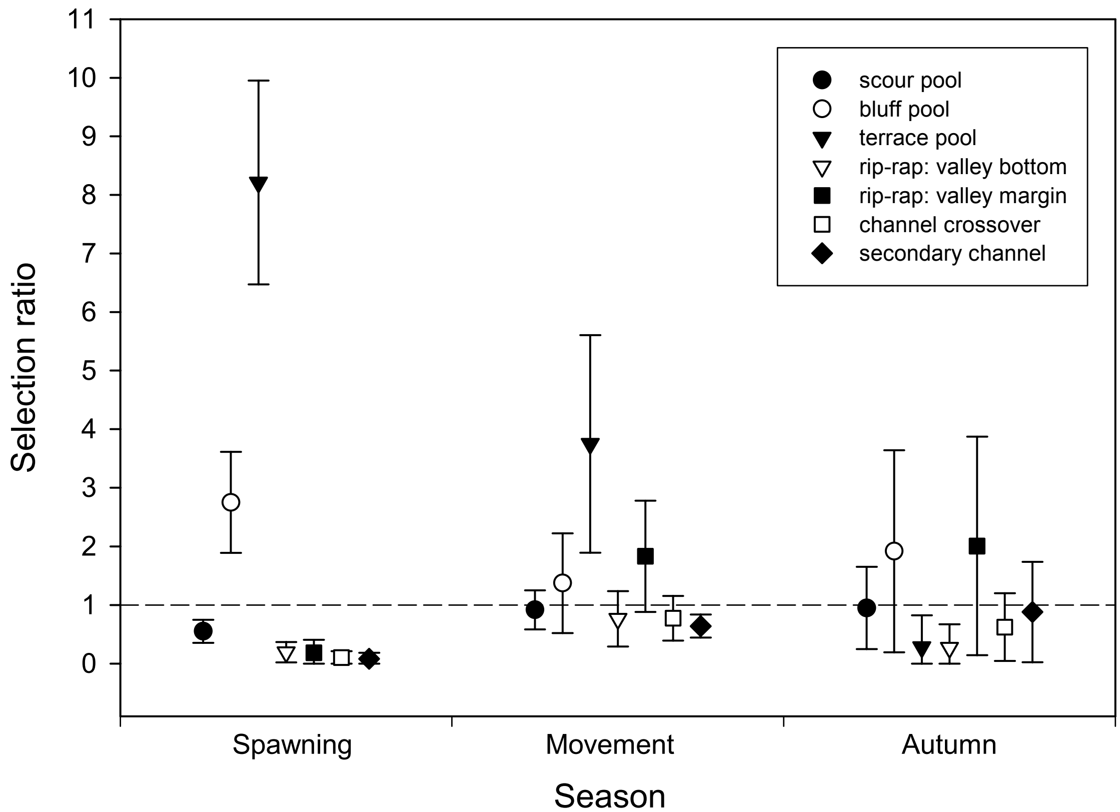


Table 1. Results of chi-square tests for resource selection of telemetered sauger by season in the Yellowstone River 2001 to 2003. The null hypothesis was resource selection in proportion to availability.

Season	X^2	d.f.	*P*
	Geologic Type		
Spawning	1228.30	455	<0.001
Movement	1085.60	595	<0.001
Autumn	351.39	102	<0.001
Winter	117.10	75	0.001
	Habitat Type		
Spawning	1537.10	546	<0.001
Movement	953.90	595	<0.001
Autumn	369.66	204	<0.001
Winter	146.83	125	0.089
	Habitat Type within Geologic Type		
Spawning	2592.1	1911	<0.001
Movement	2083.9	2975	1
Autumn	731.91	544	<0.001
Winter	263.94	200	0.002

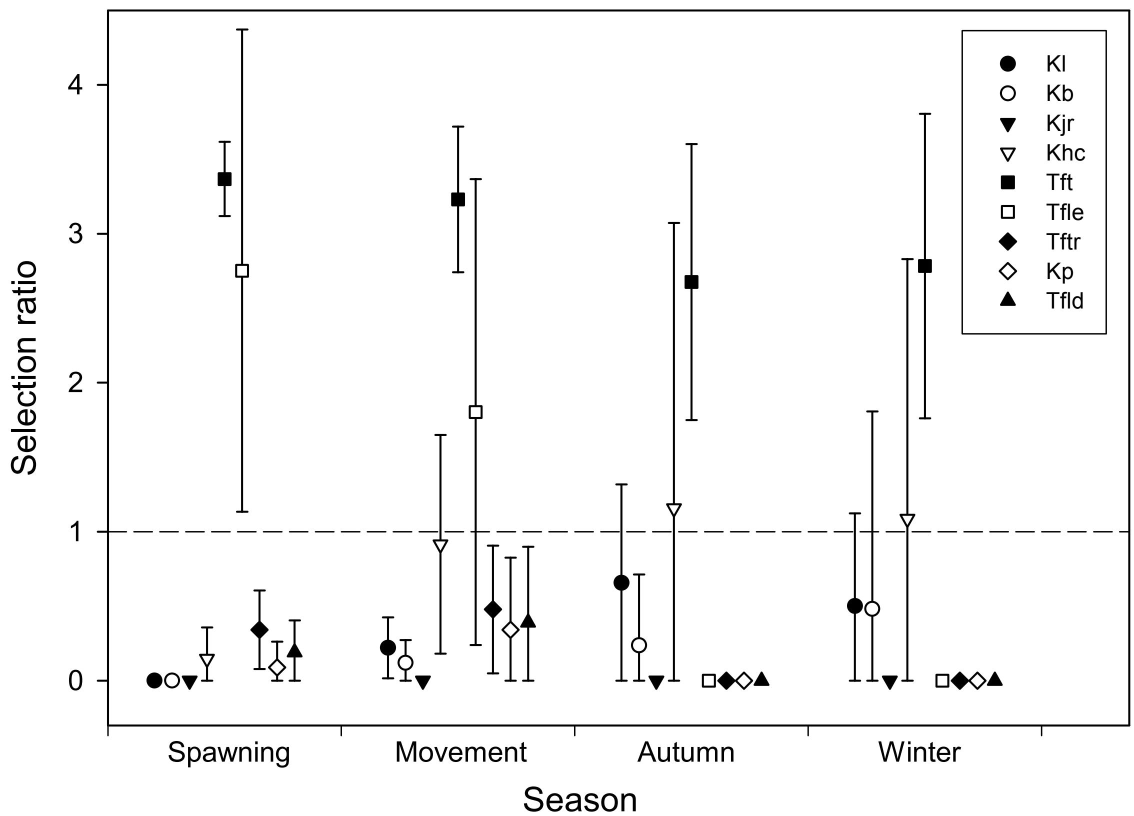
Bluff and terrace pools were positively selected during the spawning season and all other habitat types were avoided (Figure 13). Sauger demonstrated positive selection for the Tullock and Lebo members of the Fort Union Formation and avoided all other geologic types during spawning (Figure 14). However, terrace pools were used in proportion to their availability within half of the geologic types that were avoided (Figure 15). Use of tributaries for spawning by telemetered sauger was rare; one fish used the Powder River (3.3%) and no fish used the Tongue River during the spawning season in 2003.

Figure 13. Seasonal selection ratios and simultaneous 95% Bonferroni confidence intervals of habitat units of telemetered sauger in the Yellowstone River, 2001 to 2003. Values larger than 1 indicate positive selection, values less than 1 indicate negative selection, and values equal to 1 indicate use in proportion to availability.



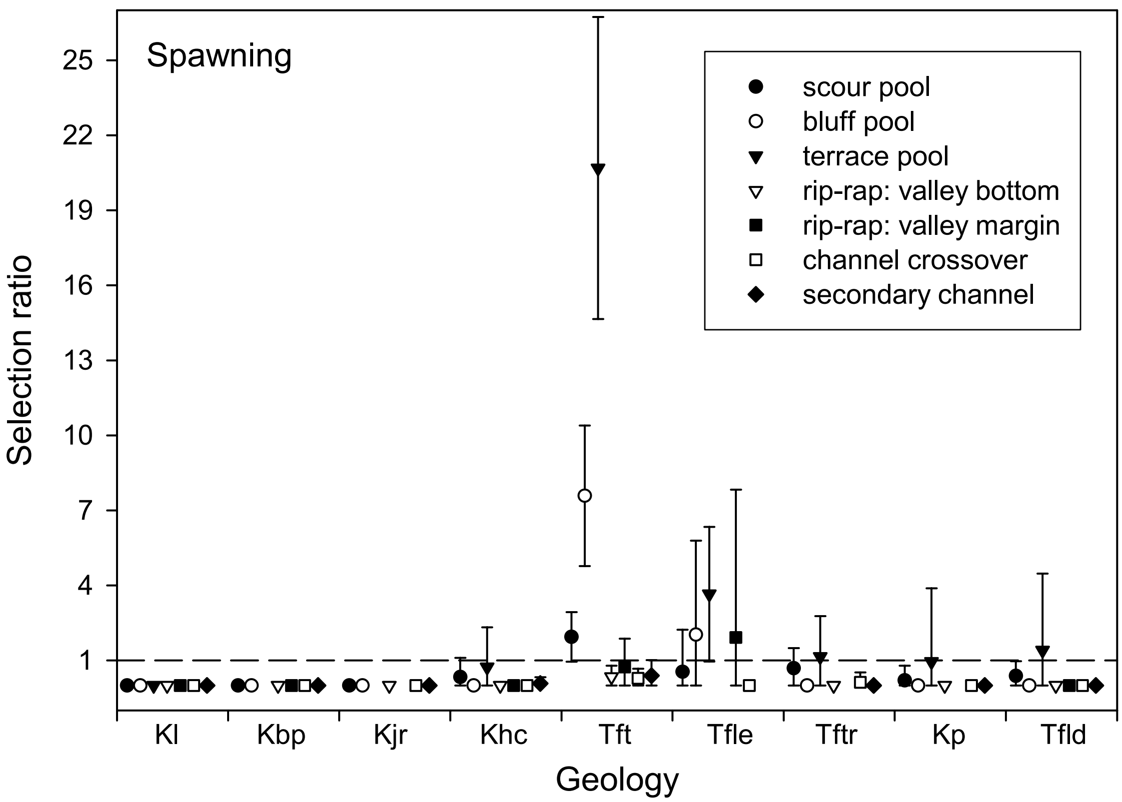
Habitat types were used in proportion to their availability during the movement season except terrace pools, which were positively selected, and secondary channels, which were negatively selected (Figure 13). However, secondary channels were the most commonly used habitat type during the movement season and negative selection resulted from their high availability throughout the study area during runoff (Table 7). Selection of geologic type during the movement season was intermediate between selection during the spawning and autumn seasons (Figure 14). Within geologic types, sauger used habitat types in proportion to their availability during the movement season (Table 1).

Figure 14. Seasonal selection ratios and simultaneous 95% Bonferroni confidence intervals of geologies by telemetered sauger in the Yellowstone River, 2001 to 2003. Values larger than 1 indicate positive selection, values less than 1 indicate negative selection, and values equal to 1 indicate use in proportion to availability. Observed geologies are Lance formation (Kl), Bearpaw Shale (Kbp), Judith River formation (Kjr), Hell Creek formation (Khc), Tullock member of the Fort Union formation (Tft), Lebo member of the Fort Union formation (Tfle), Tongue River member of the Fort Union formation (Tftr), Pierre Shale (Kp), and Ludlow member of the Fort Union formation (Tfld).



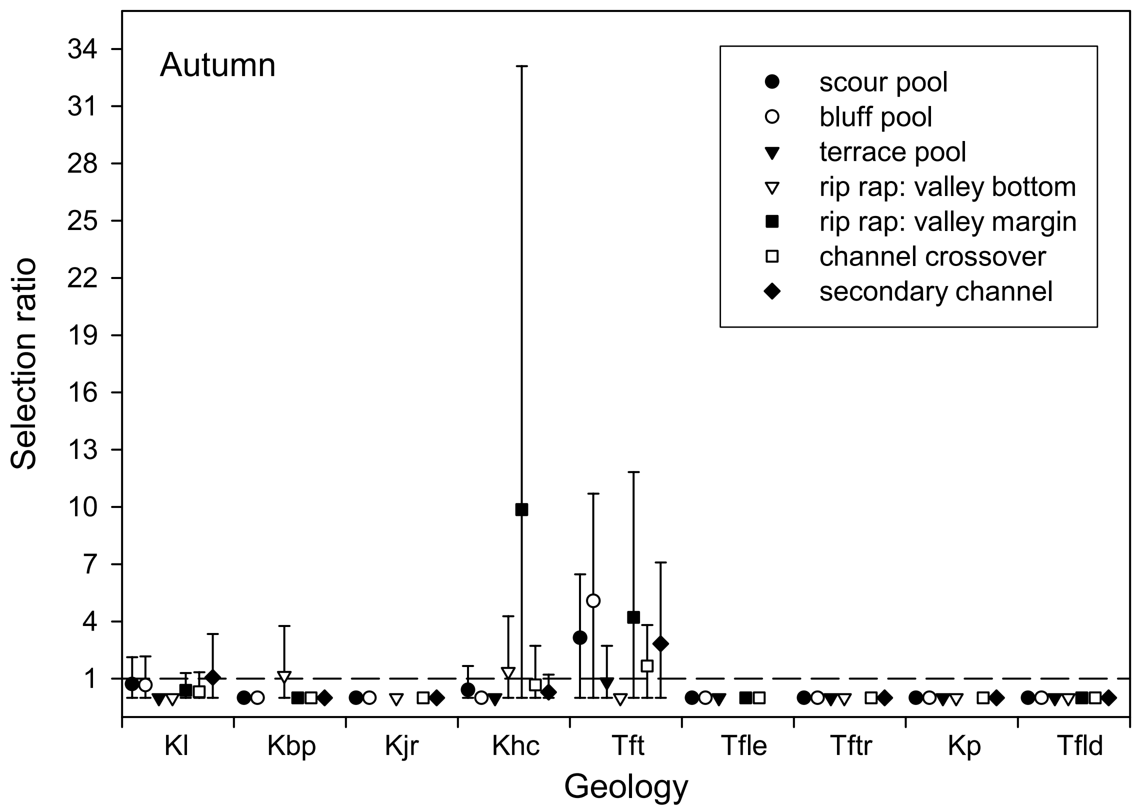
Sauger used specific geologic types during the autumn season (Figure 14), while demonstrating neutral selection for habitat types except terrace and valley bottom rip-rap pools, which were avoided (Figure 13). Within geologic types, most habitat types within the Tullock member of the Fort Union Formation and Lance and Hell Creek formations were used in proportion to their availability whereas most habitat types in all other geologic types were avoided (Figure 16).

Figure 15. Selection ratios and simultaneous 95% Bonferroni confidence intervals of habitat units within geologies during the spawning season of telemetered sauger in the Yellowstone River, 2001 to 2003. Values larger than 1 indicate positive selection, values less than 1 indicate negative selection, and values equal to 1 indicate use in proportion to availability. Observed geologies are Lance formation (Kl), Bearpaw Shale (Kbp), Judith River formation (Kjr), Hell Creek formation (Khc), Tullock member of the Fort Union formation (Tft), Lebo member of the Fort Union formation (Tfle), Tongue River member of the Fort Union formation (Tftr), Pierre Shale (Kp), and Ludlow member of the Fort Union formation (Tfld).



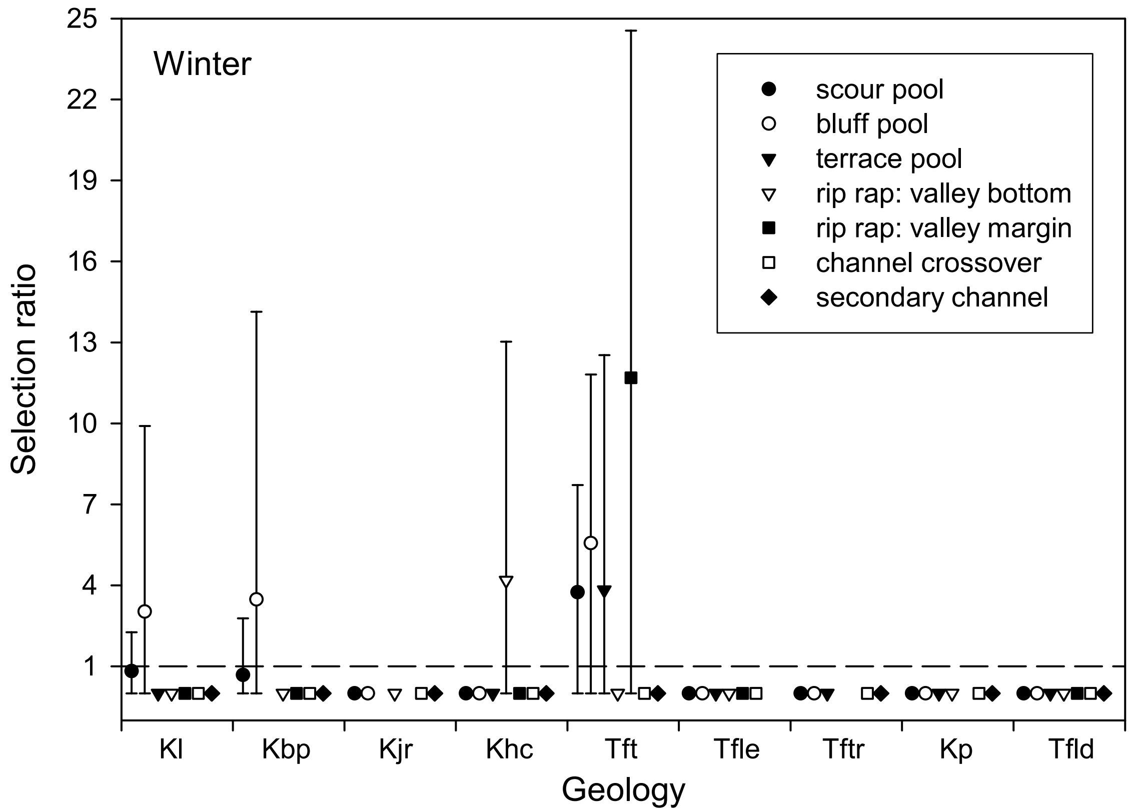
During the winter season, sauger continued to use specific geologic types (Figure 14) while using habitat types in proportion to their overall availability (Table 1). Within geologic types, scour and bluff pools were the most consistently used habitat types although rip-rap valley margin pools were used most frequently overall (Figure 17).

Figure 16. Selection ratios and simultaneous 95% Bonferroni confidence intervals of habitat units within geologies during the autumn season of telemetered sauger in the Yellowstone River, 2001 to 2003. Values larger than 1 indicate positive selection, values less than 1 indicate negative selection, and values equal to 1 indicate use in proportion to availability. Observed geologies are Lance formation (Kl), Bearpaw Shale (Kbp), Judith River formation (Kjr), Hell Creek formation (Khc), Tullock member of the Fort Union formation (Tft), Lebo member of the Fort Union formation (Tfle), Tongue River member of the Fort Union formation (Tftr), Pierre Shale (Kp), and Ludlow member of the Fort Union formation (Tfld).



In summary, terrace and bluff pools were strongly selected during the spawning period and all other habitat types were avoided. All habitat types were used during the movement season and use of geologic type was intermediate between the spawning and autumn seasons. During autumn and winter, specific geologic types were selected but most habitat types were used in proportion to their availability.

Figure 17. Selection ratios and simultaneous 95% Bonferroni confidence intervals of habitat units within geologies during the winter season of telemetered sauger in the Yellowstone River, 2001 to 2003. Values larger than 1 indicate positive selection, values less than 1 indicate negative selection, and values equal to 1 indicate use in proportion to availability. Observed geologies are Lance formation (Kl), Bearpaw Shale (Kbp), Judith River formation (Kjr), Hell Creek formation (Khc), Tullock member of the Fort Union formation (Tft), Lebo member of the Fort Union formation (Tfle), Tongue River member of the Fort Union formation (Tftr), Pierre Shale (Kp), and Ludlow member of the Fort Union formation (Tfld).



Aggregation

Sauger were significantly aggregated over their entire observed spatial distribution during a two-to-three week period associated with spawning in late April and early May (Figure 18 a & f). Aggregations occurred from the confluence with the Tongue River to below Intake Diversion. Telemetered fish were distributed over a distance of 116-146 km and patch length ranged from 3 to 6 km during this time. The value of crowding within a patch ranged from 1 to 3 telemetered sauger above the number that would be expected if they were randomly distributed. Intensity of aggregation began to decrease and an intermediate pattern of distribution was observed at most spatial scales during the period of upstream movement following spawning (Figure 18 b). Distributions of over 400 kilometers, the widest of the year, occurred during this time period. Sauger were significantly randomly distributed at all spatial scales during late summer, autumn (Figure 18 c) and winter (Figure 18 d) sedentary periods and the early spring (figure 18 e) period of downstream movement. Distribution during the sedentary periods ranged from 200 to 325 kilometers but decreased rapidly in the spring as fish began to move back into their spawning range. Significant aggregation at most spatial scales began to occur again during April and was associated with spawning (Figure 18 f). This seasonal pattern of spatial association occurred during all years of the study (Figure 19). Scales at which significantly different spatial associations occur for each week's telemetry relocations are summarized in Appendix C.

Figure 18. Seasonal variation in the distribution and spatial association of sauger telemetered in the lower Yellowstone River. Plots on the left display the distributions of telemetered sauger during given time periods. River location describes the distance from the confluence with the Missouri River. Plots on the right describe the corresponding spatial associations. The solid line, L(*t*), represents the number of neighbors observed beyond those that would be expected if sauger were randomly distributed at spatial scale *t*. The distribution is significantly aggregated ($P \leq 0.10$) at spatial scale *t* when L(*t*) is above the upper 90% confidence band shown by the dashed lines.

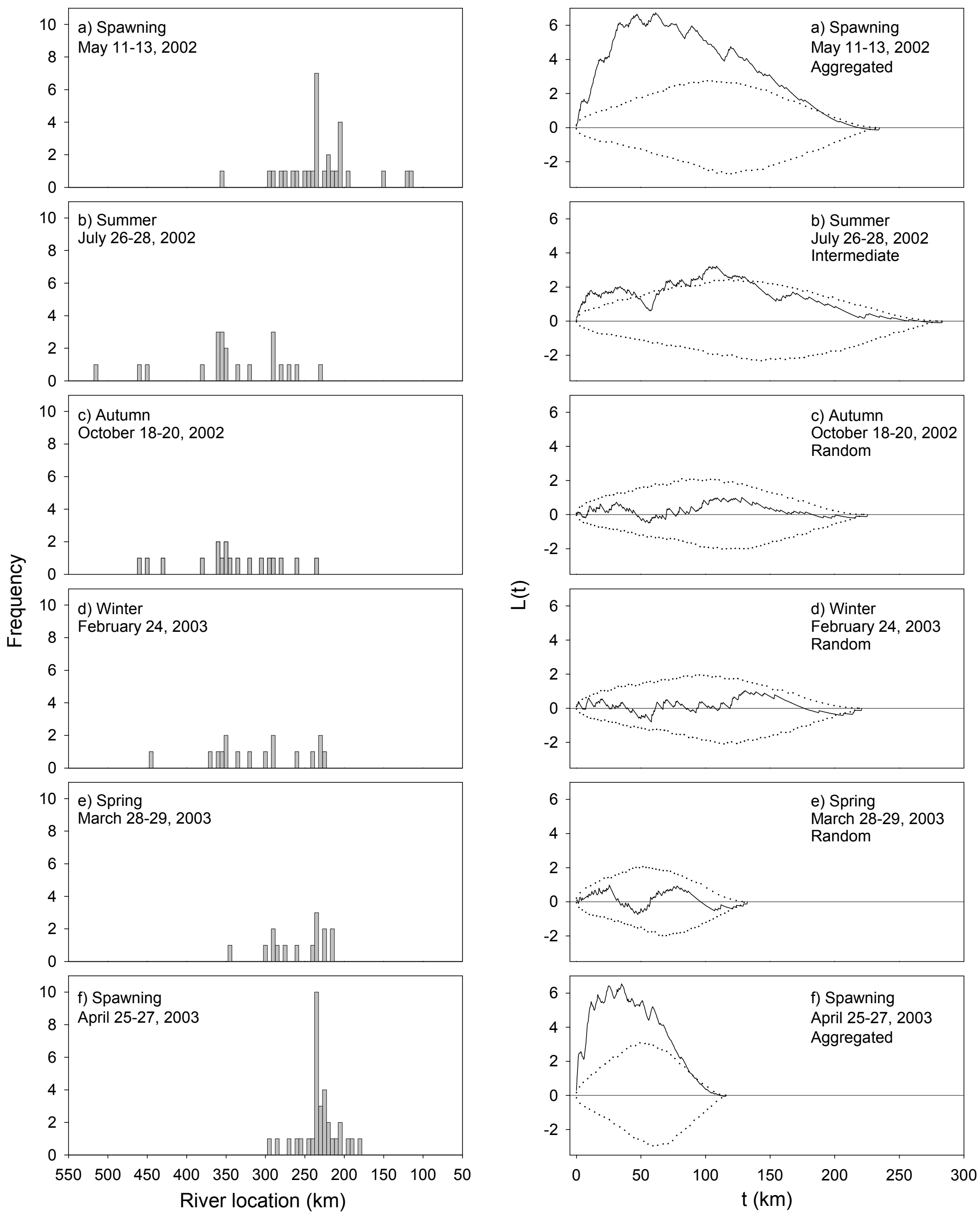
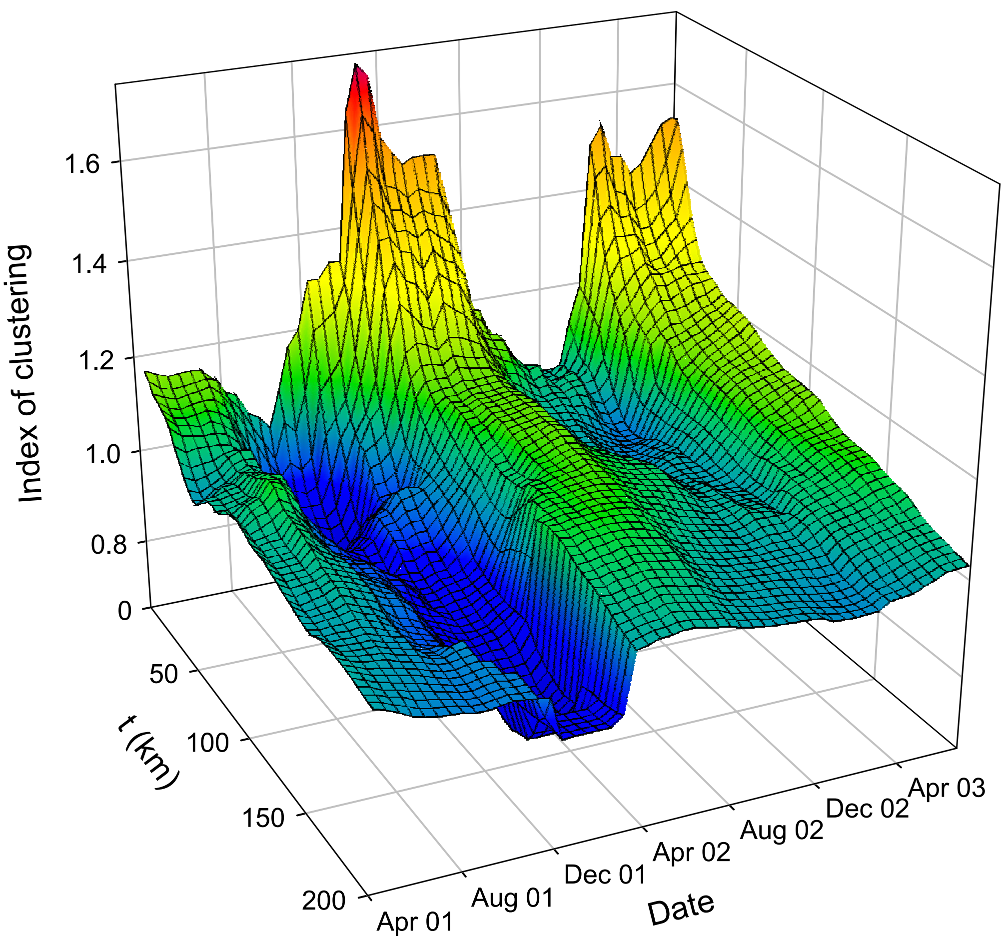


Figure 19. Index of clustering of telemetered sauger in the lower Yellowstone River, 2001 to 2003. For a given spatial scale *t*, values greater than 1 (red, yellow, green) indicate aggregated distribution, values near 1 indicate random distribution (dark green, blue), and values less than 1 indicate uniform distribution (dark blue).



<u>Exploitation</u>

Immediate tag shedding probability was 0.04115, instantaneous daily probability of continuous tag shedding was 0.00031, and tag reporting probability was 0.385. Brownie models were robust to the tagging regime used in this study; simulations indicated that the methods used resulted in unbiased survival and exploitation estimates on average (Table 2). The most general model from each group of candidate models adequately fit the data based on the *P*-values obtained from goodness-of–fit testing (Table 3). Overdispersion was detected for the models used to estimate annual exploitation and was adjusted for accordingly (Table 3). Model output for annual and seasonal models is presented in Appendix D.

Table 2. Results of simulations testing the ability of Brownie models to predict true parameter values when all fish were not tagged prior to the beginning of the fishing season. Mean estimated values and 95% confidence intervals were obtained by model averaging based on AICc weights from 100 simulated data sets and models parameterized using program MARK. Confidence intervals are shown in parentheses.

Parameter	True value	Mean estimated value
Survival: year 1 (S_1)	0.680	0.654 (0.282, 0.858)
Survival: year 2 (S_2)	0.520	0.575 (0.221, 0.827)
Probability of capture: year 1 (f_1)	0.090	0.093 (0.047, 0.178)
Probability of capture: year 2 (f_2)	0.220	0.214 (0.138, 0.315)
Probability of capture: year 3 (f_3)	0.220	0.216 (0.119, 0.357)

Table 3. Results of goodness-of-fit testing for models used to estimate survival and exploitation of sauger on the lower Yellowstone River, 2001 to 2003.

Parameters of interest	Model tested	GOF *P*-value	c-hat
Annual probability of survival and capture	S(t)f(t)	0.5702	1.00
Annual probability of exploitation	S(t)f(t)	0.0773	3.12
Seasonal probability of survival and capture	S(t)f(t)	0.3928	1.00
Seasonal probability of exploitation	S(t)f(t)	0.7889	1.00

Annual survival was estimated at 72.6% in 2001 and 68.2% in 2002 using T-bar tag data and apparent annual survival was estimated as 51.9% in 2001 and 51.6% in 2002 from the telemetry data (Table 4). Annual capture rates were about 30% and annual exploitation rates ranged from 15.9 to 20.1% during 2001 to 2003 (Table 4).

Table 4. Annual estimates of survival and exploitation parameters for sauger on the lower Yellowstone River, 2001 to 2003. $\Phi_{telemetry}$ (probability of apparent survival) was estimated using known fate models and data from telemetered sauger and $S_{T\text{-}tag}$ (probability of survival), f (probability of being caught), u (probability of being harvested), and v (expectation of non-fishing mortality) were estimated using Brownie models and data from T-bar tagged sauger. Estimates and 95% confidence intervals were derived by model averaging based on AICc or QAICc weights or using the delta method. Confidence intervals for parameter estimates are shown in parentheses.

Year	$\Phi_{telemetry}$	$S_{T\text{-}tag}$	f	u	v
2001	0.519	0.726	0.300	0.159	0.115
	(0.336, 0.696)	(0.529, 0.925)	(0.237, 0.372)	(0.072, 0.318)	(0.000, 0.310)
2002	0.516	0.682	0.302	0.198	0.120
	(0.345, 0.683)	(0.492, 0.871)	(0.247, 0.364)	(0.123, 0.303)	(0.000, 0.300)
2003	--	--	0.323	0.201	--
			(0.256, 0.398)	(0.123, 0.311)	

Apparent seasonal survival rates during 2001 and 2002 were 80.4 and 78.2% during the spawning-movement period, 80.1 and 81.7% during the autumn period, and 81.6 and 81.0% during the winter period (Table 5). During the spawning-movement period, capture rates ranged from 4.8 to 15.4% and exploitation rates ranged from 1.3 to 4.4% (Table 5). During the autumn period, capture rates ranged from 23.7 to 77.2% and exploitation rate increased from 14.5% in 2001 to 38.7% in 2003 (Table 5). Most of the mortality that occurred during the spawning-movement period appeared to be related to non-fishing sources and almost all of the mortality that occurred during the autumn period was related to exploitation (Table 5). Annual and seasonal tag returns by tagging cohort are summarized in Appendix D.

Table 5. Seasonal estimates of survival and exploitation parameters of sauger on the lower Yellowstone River, 2001 to 2003. $\Phi_{telemetry}$ (probability of apparent survival) was estimated using known fate models and data from telemetered sauger and f (probability of being caught), u (probability of being harvested), and v (expectation of non-fishing mortality) were estimated using Brownie models and data from T-bar tagged sauger. Estimates and 95% confidence intervals were derived by model averaging based on AICc weights or using the delta method. Confidence intervals for parameter estimates are shown in parentheses.

Year	Season	$\Phi_{telemetry}$	f	u	v
2001	spawning-movement	0.804 (0.682, 0.887)	0.154 (0.085, 0.263)	0.031 (0.008, 0.114)	0.165 (0.059, 0.271)
2001	autumn	0.801 (0.672, 0.888)	0.772 (0.056, 0.995)	0.145 (0.052, 0.341)	0.054 (0.000, 0.162)
2001	winter	0.816 (0.679, 0.903)	0.00	0.00	0.184 (0.087, 0.280)
2002	spawning-movement	0.782 (0.642, 0.878)	0.114 (0.066, 0.189)	0.044 (0.019, 0.103)	0.174 (0.073, 0.274)
2002	autumn	0.817 (0.674, 0.906)	0.237 (0.177, 0.310)	0.195 (0.137, 0.269)	0.000 (0.000, 0.112)
2002	winter	0.810 (0.672, 0.899)	0.00	0.00	0.190 (0.098, 0.282)
2003	spawning-movement	--	0.048 (0.027, 0.085)	0.013 (0.004, 0.040)	--
2003	autumn	--	0.628 (0.476, 0.758)	0.387 (0.248, 0.546)	--
2003	winter	--	0.00	0.00	--

Entrainment

The annual probabilities of entrainment in Intake Canal were 0.065 in 2001 and 0.094 in 2002 (Table 6). These rates represent 29.4 and 47.7% of the annual non-fishing mortality.

Table 6. Estimated entrainment in Intake Diversion of sauger tagged upstream of Intake Diversion in the lower Yellowstone River, 2001 and 2002. Canal resident exploitation rate refers to the probability of a sauger being captured by anglers once entrained.

Year	Canal resident exploitation rate	# tagged sauger entrained and captured	Estimated # tagged sauger entrained	Annual probability of entrainment
2001	0.741	4	5	0.065
2002	0.435	5	12	0.094

DISCUSSION

Movement

Movement patterns of Yellowstone River sauger are unique, but influences of impoundments elsewhere make comparisons difficult. For example, annual migrations between spawning and home areas in the Yellowstone River (mean 89.5 km) are among the longest reported, but impoundments preclude similar movement distances in other systems (Nelson 1968; Hesse 1994; St. John 1990; Pegg et al. 1997). Downstream migration to spawning areas is also unique to the Yellowstone River, but only upstream migrations to riverine habitats are possible elsewhere (Nelson 1969; St. John 1990; Pegg et al. 1997). Timing of migration also differed. Sauger in the Yellowstone River migrated to spawning areas in spring after over-wintering in the same areas used during summer and autumn. Earlier, two-stage migrations were reported for dam-influenced populations; sauger moved out of reservoirs in autumn and over-wintered in tailwaters below dams before moving to nearby spawning areas in spring (Nelson 1968; St. John 1990; Pegg et al. 1997). Accordingly, lotic habitats may be preferred during winter, especially where hypolimnetic discharges afford favorable conditions (Marcy and Galvin 1973; Crance 1987). Conversely, harsh winter conditions (spring ice flows and jams near spawning areas; Cunjak 1996) in the Yellowstone drainage at the western edge and altitudinal extremes of sauger distribution (Scott and Crossman 1973; White and Bramblett 1993) may delay migration until spring.

Yellowstone River sauger displayed fidelity to spawning and home locations. Sauger reoccupied individual home-location habitat units but were less faithful to spawning habitat units; 8 of the 11 sauger relocated during consecutive spawning periods used the same individual habitat unit as used in the year before. Fidelity to spawning and home location is common for walleye (Olson et al. 1978) but was previously not described for sauger.

Larger sauger were more efficient at spawning and migrating, possibly because of body-size influenced intra- and inter-sexual selection. Larger fish are more likely to occupy and defend higher quality mating areas (Keenleyside and Dupuis 1988; Van Den Berghe and Gross 1989) and are more frequently selected as mates (Sargent et al. 1986; Hutchings et al. 1999) potentially allowing larger sauger to complete spawning more efficiently. Earlier migration may also be facilitated by past experience. In walleye, repeat migrations reinforce learned homing behavior resulting in more deliberate movements by experienced fish (Olson et al. 1978).

Diversion dams on the Yellowstone River did not appear to restrict the movements of adult sauger as had been hypothesized (Graham et al. 1979; Swedberg 1985; Helfrich et al. 1999; McMahon and Gardner 2001), but evidence thereof was equivocal. Movements were observed past all dams except Huntley Diversion, but it was encountered by few telemetered sauger. Spawning and home locations of most telemetered sauger (80%) were between Cartersville and Intake Diversions such that no dams were encountered during their migrations; however, this may be an artifact of tagging locations. Sauger with home locations upstream of Cartersville Diversion were significantly longer than those that had downstream home locations (t-test, P = 0.048), suggesting that this dam was a size-dependent barrier, but larger fish may simply migrate further. Sauger as small as 385-mm successfully passed this dam. Consecutive relocations immediately below the dam were rare, indicating the absence of passage delays, but these movements were likely facilitated by concurrent high discharges; movements at other times of the year, when discharge was low and dam passage may be hindered, were rare. However, during each autumn, at least one telemetered sauger was relocated immediately below this dam and may have been prevented from moving past it. Conversely, they may have simply selected this habitat. Whereas the effects of these dams on passage by adult sauger are unclear, evidence of restricted upstream movement of juveniles exists (Penkal 1992).

Habitat use

Presence of boulder and bedrock substrates influenced selection of habitats during spawning. Geologic types characterized by reef-forming bedrock outcrops (Silverman and Tomlinsen 1984) and bluff and terrace pool habitats, which recruit boulder-sized substrate from hill slopes (Rabeni and Jacobson 1993), were selected and all other geologic and habitat types were avoided. Sauger spawning is often associated with large, rocky substrates and bedrock reefs (Nelson 1968; Gardner and Stewart 1987; St. John 1990; Hesse 1994) and turbid, warm tributaries (B. Graeb, South Dakota State University, Brookings, South Dakota, personal communication); most spawning in the Yellowstone River occurred downstream of the Powder River.

Yellowstone River sauger spawned in more locations than were previously known and spawning habitat did not appear limited. To date, spawning habitat was thought to be scarce; only three discrete spawning areas had been documented (Penkal 1992) and one of these, the Tongue River, is no longer suitable because of chronic dewatering (McMahon and Gardner 2001). However, telemetered sauger used many spawning areas from the confluence with the Tongue River to below Intake Diversion with the most concentrated activity occurring between the Powder River and O'Fallon Creek. Ostensibly suitable spawning habitats were not rare although they were confined to discrete reaches of stream where large, rocky substrates were common.

Telemetered sauger spawned almost exclusively in mainstem habitats whereas previous studies suggested that most spawning occurs in the Tongue and Powder rivers (Penkal 1992; McMahon and Gardner 2001). Rare tributary use was consistent with previously reported declines (McMahon and Gardner 2001) and low electrofishing catch rates in the Tongue and Powder rivers in 2003 (M. Backes, Montana Fish, Wildlife and Parks, Miles City, Montana, personal communication). Mean April Tongue River discharge was well below minimum sauger spawning and passage requirements (Elser et al. 1977) during each year of the study. However, better conditions occurred in the Powder River; mean April discharge was about 70% of the 66-year average in 2003. The failure of sauger to use the Powder River despite improved discharge may be influenced by learned homing behavior (Olson et al. 1978); disruption of tributary spawning during drought conditions may have resulted in failure to transfer tributary migration behavior to younger age classes. It is also possible that higher discharges than those observed during this study are required for tributary spawning. Spawning success and larval and juvenile survival may differ between tributaries and the mainstem.

Home river locations were most strongly influenced by geologic type. Selected geologic types of the Tullock member and Lance and Hell Creek formations had irregular valleys that were narrower, more resistant, and exhibited more control on channel margins than did avoided reaches (Silverman and Tomlinsen 1984). Bearpaw shale valley margins tend to slope back and fail as river meanders migrate into them whereas the harder, more resistant sandstones of the Tullock member and Lance and Hell Creek formations maintain an asymmetric channel cross section with deep, vertical cutbanks, leaving little impetus for the channel to migrate and allowing formation of deeper and longer pools (K. Boyd, Applied Geomorphology Incorporated, Bozeman, Montana, personal communication). Relationships between geologic type and channel morphology have not been quantified; however, more erosive channel margins in avoided reaches likely result in higher width-to-depth ratios, lower velocities and depths, and a more braided channel pattern (K. Boyd, personal communication). Geologic types used for spawning are likely not used as home river locations because of low complexity; spawning areas are dominated by bluff and terrace pools whereas the most heavily used geologic types had higher habitat diversity and complexity.

Aggregation

The number and distribution of spawning aggregations were larger than previously known. Previous studies suggested that all spawning in the lower Yellowstone River was concentrated in relatively short sections of Tongue and Powder rivers (Penkal 1992; McMahon and Gardner 2001). In contrast, I found that many mainstem aggregations occurred and were distributed over 250 kilometers of the

Yellowstone River and tributary spawning was rare. Aggregation patch length (3 to 6 kilometers) was consistent with bluff and terrace pool length and, on average, there were about two to three times as many telemetered sauger as expected if they were randomly distributed. However, larger aggregations were observed; 28 to 36% of the telemetered sauger were relocated within 6 kilometers of the mouth of the Powder River during the week of peak spawning each year.

Fewer aggregations were observed in other systems (Nelson 1968; Gardner and Stewart 1987; St. John 1990; Pegg et al. 1997) than in the Yellowstone River. The large number and distribution of spawning aggregations in the Yellowstone River may represent spatial patterns of sauger in the absence of mainstem impoundments, which restrict movements to some degree in the other systems.

Sauger in the Yellowstone River were aggregated for a shorter duration than in other systems. Aggregations resulting from impeded autumn and winter migrations caused by mainstem impoundments occurred as early as November elsewhere (Nelson 1968; Pegg et al. 1997). Aggregations formed later in the Yellowstone River because of relatively late migrations (March to April) to spawning areas and did not occur at diversion dams because of ostensibly easy passage.

Exploitation

Harvest by anglers likely does not prevent recovery of the Yellowstone River sauger population. Relatively low exploitation (15-20%) and high survival (68-73%) rates were observed. High survival rates are corroborated by the length-determined age structure of sauger collected for this study; about half of the fish tagged were 5 to 10 years old (Haddix and Estes 1976; Carlander 1997). High proportions of old fish are characteristic of lightly exploited stocks (Van Den Avyle and Hayward 1999). Elsewhere, decline or collapse of sauger populations occurred when exploitation rates were 30-90% and survival rates were less than 30%; these populations were comprised almost exclusively of age 1 and 2 individuals (Pegg et al. 1996; Maceina et al. 1998). However, the apparent propensity for juvenile sauger in the Yellowstone River to rear downstream of the study area may have artificially skewed the observed age structure (Penkal l992).

The potential exists for seasonally high exploitation of Yellowstone River sauger. Most harvest in overexploited sauger populations occurs during extended periods of aggregation (Pegg et al. 1996; Maceina et al. 1998); however, Yellowstone River exploitation rates were lower (1 to 4%) during the spawning-movement aggregation season than when sauger were randomly distributed in autumn (14 to 39%). Although anglers target primary areas of aggregation, the short duration and large number of aggregations likely reduce risk of overexploitation. However, potential for high exploitation exists at the Powder River aggregation because of its comparatively large size and popularity. Even greater potential for high exploitation exists during autumn; capture rate was high (24 to 77%) but voluntary release (37%) maintained lower exploitation rates. High autumn capture (63%) and exploitation (39%) rates in 2003 may have been biased given the low annual exploitation rate (20%); increased angler reporting rate late in the study may account for the high seasonal capture and exploitation rates observed. Nonetheless, annual exploitation estimates would increase to over 30% if all captured sauger were harvested. Because the potential for high harvest exists, exploitation rates should continue to be monitored.

Tag loss and non-reporting were uncharacteristically high for Yellowstone River sauger. The probability of a sauger losing both tags was low but the probability of losing a single tag was relatively high. Single tag loss rates by sauger over a 5-month period were 0 and 4.5% in the Tennessee River (Pegg et al. 1996; Maceina et al. 1998) but were 15.5% in the Yellowstone River. Small sample size may have biased tag loss estimates from the Tennessee River studies; more double-tagged sauger were caught and reported during this study, resulting in about five times less sampling variation. Conversely, high tag loss rates in the Yellowstone River may be explained by use of anglers as taggers (Schwartz 2000); however, only three anglers were used as taggers, they were well trained in species identification and tagging location, and biologists tagged the majority of the sauger. The low reporting rate (38.5%) observed on the Yellowstone River was consistent with studies offering no reward for returning tags or bands (Nichols 1991; Zale and Bain 1994). Reporting rates of 64 to 67%, which are commensurate with a US$22 reward, were observed in other studies offering limited-edition reward caps (Zale and Bain 1994). The failure of this incentive type to elicit a similar response on the Yellowstone River suggests that its value is regionally variable and that cash rewards may be a more effective and cost efficient means of enhancing reporting rates.

Estimates of annual and seasonal apparent survival from telemetry data were downwardly biased compared to those from T-bar tag data. The most likely cause of bias is underestimation of transmitter failure rates, which were equivocal without estimates of precision or description of how they were determined. Evidence of mortality sensor failure also existed. For example, a transmitter emitted a mortality signal for several consecutive weeks and no movements were observed causing the sauger to be deemed a mortality; however, the “deceased” sauger was caught two years later and its transmitter returned. Additionally, an angler reported mistakenly assuming a transmitter antenna protruding from the body of a captured sauger was a wire fishing leader being expelled through the gut and removing the antenna, resulting in loss of signal and the sauger to be erroneously regarded as a mortality. Emigration may have also been a source of bias, although tributary use was rare and a wide mainstem area was searched.

Entrainment

Entrainment in irrigation diversions was a primary source of non-fishing mortality. Most mortality that occurs during the spawning-movement period is related to non-fishing sources and as much as half is related to entrainment in Intake Canal. It is likely that entrainment occurs to some degree at the other five diversion dams, potentially making it the primary source of non-fishing mortality to adult sauger. Furthermore, most entrained sauger were less than 3 years old (Hiebert et al. 2000) creating the possibility that higher entrainment-caused mortality rates exist for juveniles than adults monitored in my study. Reduction of entrainment in irrigation diversions should be considered a priority for sauger recovery.

Summary of Findings

Diversion dams did not appear to affect movements or habitat use of adult sauger. Most sauger did not encounter diversion dams during annual migrations between spawning and home locations. Diversion dams separated seasonally important habitat types of some sauger but movement was not ostensibly restricted. Because sauger were able to pass diversion dams relatively quickly, significant aggregations did not occur downstream of these structures.

Spawning habitat did not appear to be scarce in the Yellowstone River. Sauger used mainstem areas distributed over 250 kilometers for spawning. Spawning habitats were associated with large, rocky substrates and bedrock reefs. Use of tributaries for spawning was rare.

Exploitation rates were low overall but the potential for seasonally high exploitation exists. Exploitation rates were lower in spring when sauger were aggregated than in autumn when they were randomly distributed. The large number of aggregations observed further reduces the possibility of overexploitation although a substantial aggregation occurred at the Powder River. The probability of individual sauger being captured in autumn is high and low exploitation rates result from voluntary release of captured fish. Exploitation rates would increase to potentially deleterious levels if all captured sauger were harvested.

Entrainment in irrigation diversions is a major source of mortality to the Yellowstone River sauger population. Entrainment in Intake diversion alone accounts for about half of non-fishing mortality. Entrainment in irrigation canals may cumulatively be the single largest non-fishing source of mortality to adult sauger in the Yellowstone River.

Implications for Recovery

Migratory barriers, overexploitation, and entrainment in irrigation diversions were not likely principally responsible for the failure of Yellowstone River sauger to return to historical abundances. Mainstem spawning and home location habitats were widely available and diversion dams did not noticeably restrict access, although tributary use is now rare. The relatively high survival rates observed make it unlikely that angler harvest or entrainment of adult sauger was solely responsible for limiting recovery.

Increased abundances of sauger in recent years confirm that examined factors are unlikely to prevent recovery. Average electrofishing catch rates improved from 2 sauger per hour during 1992 to 1997 to 8 sauger per hour during 1998 to 2002 (M. Backes, personal communication); pre-decline catch rates averaged 12 sauger per hour (McMahon and Gardner 2001). McMahon (1999) anticipated a delayed response of 4 years between favorable discharge conditions and increased abundances but a 7-year lag was observed. Lengthy lag periods suggest that factors in addition to discharge influenced abundances; however, factors affecting juvenile survival and year class strength in the Yellowstone River are poorly understood.

Habitat alteration in combination with expanding populations of nonnative piscivores may affect recovery of Yellowstone River sauger. Competition with and predation by smallmouth bass and walleye have been suggested to explain the limited recovery (McMahon and Gardner 2001). Direct competition is likely rare because of dissimilar habitat preferences; sauger are more abundant in areas of relatively high turbidities (Nelson and Walburg 1977; Fitz and Holbrook 1978; Rawson and Scholl 1978). However, tributary impoundments increase Yellowstone River water clarity, which may result in replacement by walleye (Nelson and Walburg 1977) and smallmouth bass (McMahon and Gardner 2001). Lentic conditions behind impoundments also favor walleye over sauger (Nelson and Walburg 1977); pools formed by diversion dams and extensive stream bank armoring may create these conditions in the Yellowstone River. Increased predation on juveniles by walleye and smallmouth bass may also limit sauger recovery (Zimmerman 1999; McMahon and Gardner 2001).

Although the primary factors preventing Yellowstone River sauger from returning to historical abundances remain unclear, reducing mortality rates may facilitate recovery. Eliminating entrainment will likely be a more effective restorative action than restricting angler harvest. My findings suggest that eliminating entrainment in irrigation diversions will reduce annual mortality of adult sauger by at least 24 to 30% barring a compensatory response. Because the majority of entrained sauger are juveniles (Hiebert et al. 2000) even larger reductions in juvenile mortality rates are likely. Abundances of adult sauger would be bolstered by reduced mortality combined with increased juvenile recruitment. Allowing anglers to continue harvesting sauger insures that they will remain concerned about the status of the population, thereby providing important political motivation for sauger recovery.

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APPENDICES

APPENDIX A

RELOCATION HISTORIES

Figure 20. Movements of sauger 48.051 (N=3) during 2001 and 2002 in the Yellowstone River, Montana.

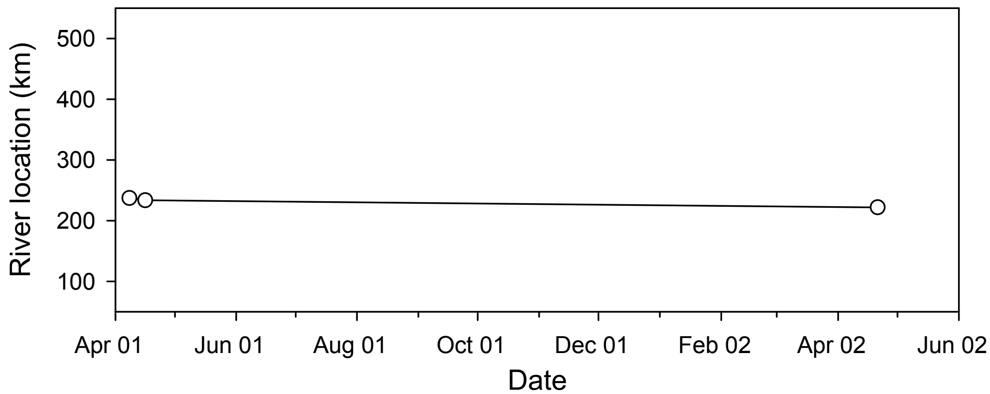


Figure 21. Movements of sauger 48.431 (N=4) during 2001 and 2002 in the Yellowstone River, Montana.

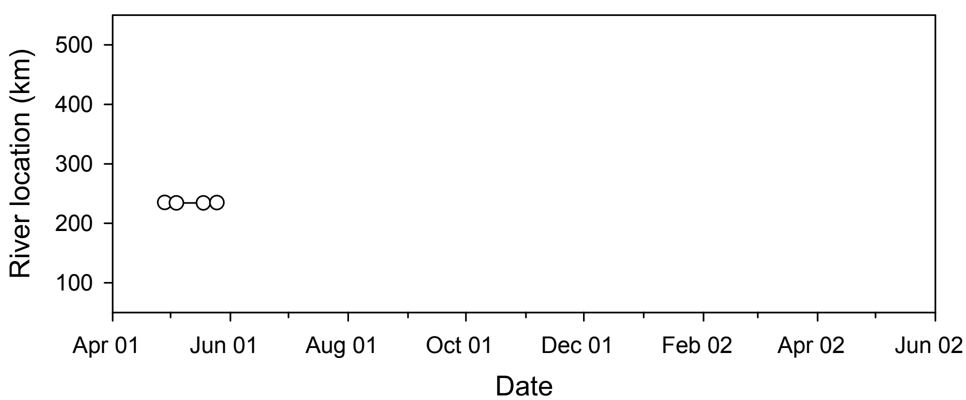


Figure 22. Movements of sauger 48.241 (N=4) during 2001 and 2002 in the Yellowstone River, Montana.

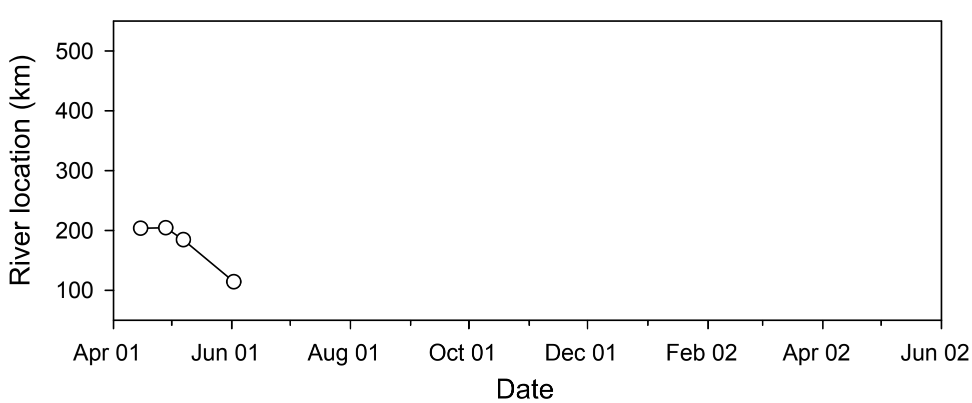


Figure 23. Movements of sauger 48.351 (N=4) during 2001 and 2002 in the Yellowstone River, Montana.

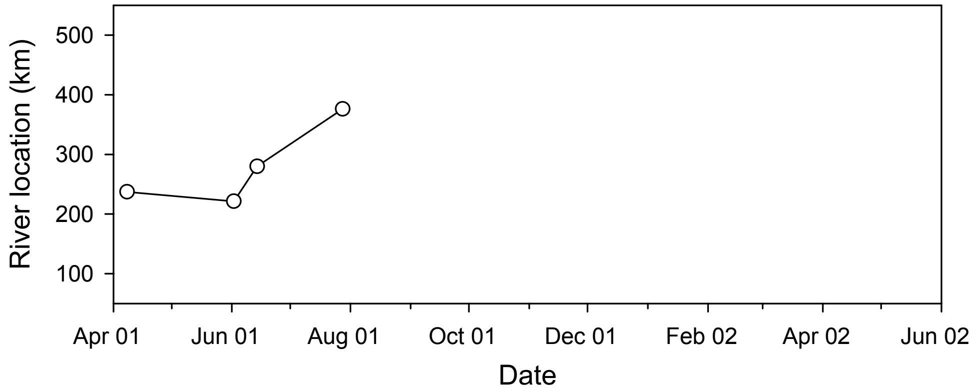


Figure 24. Movements of sauger 48.301 (N=4) during 2001 and 2002 in the Yellowstone River, Montana.

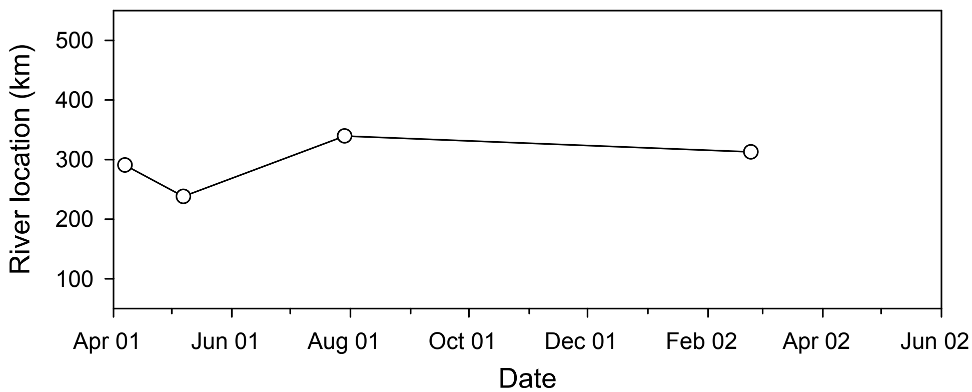


Figure 25. Movements of sauger 48.412 (N=6) during 2001 and 2002 in the Yellowstone River, Montana.

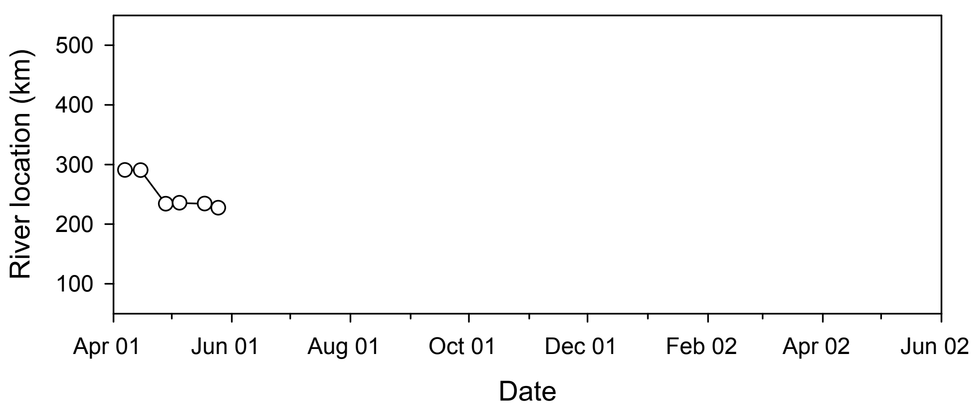


Figure 26. Movements of sauger 48.281 (N=6) during 2001 and 2002 in the Yellowstone River, Montana.

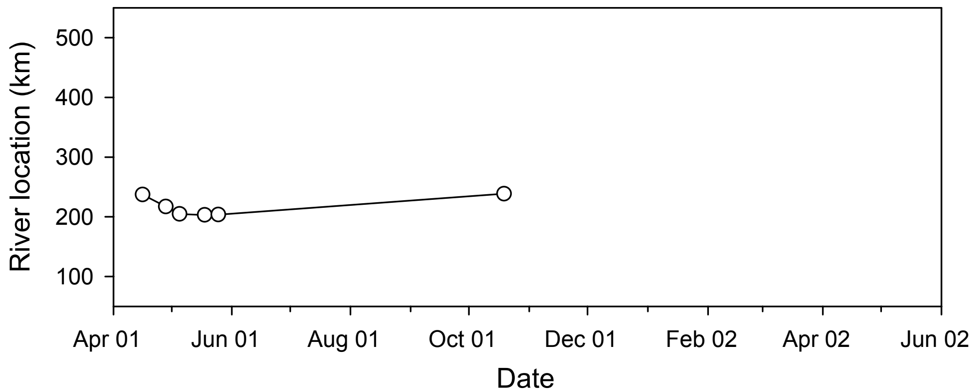


Figure 27. Movements of sauger 48.111 (N=6) during 2001 and 2002 in the Yellowstone River, Montana.

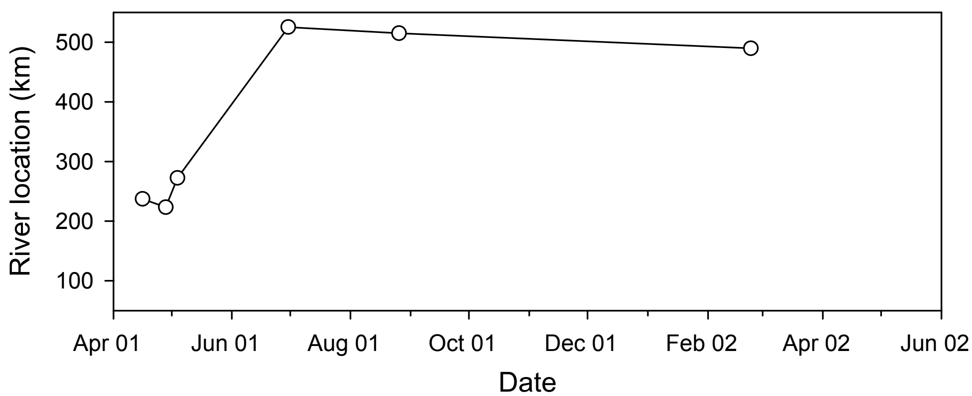


Figure 28. Movements of sauger 48.072 (N=7) during 2001 and 2002 in the Yellowstone River, Montana.

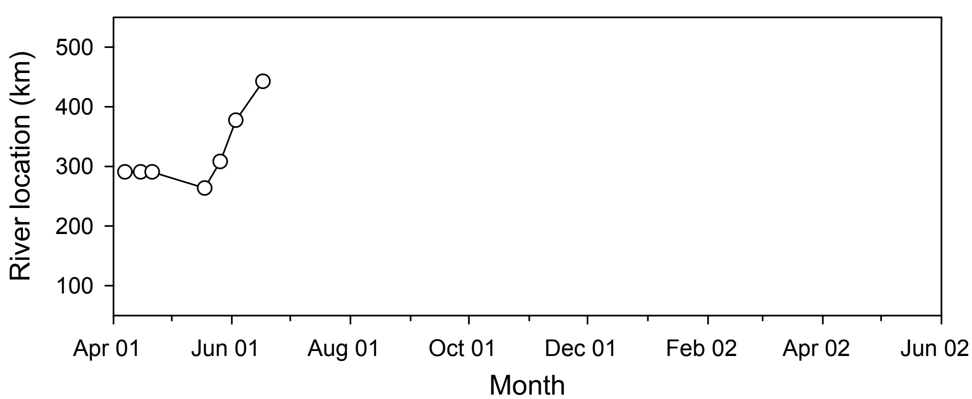


Figure 29. Movements of sauger 48.032 (N=7) during 2001 and 2002 in the Yellowstone River, Montana.

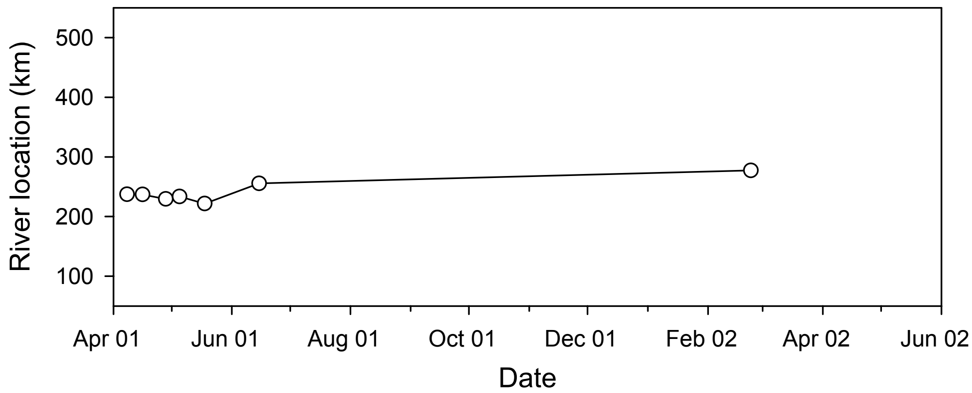


Figure 30. Movements of sauger 48.372 (N=7) during 2001 and 2002 in the Yellowstone River, Montana.

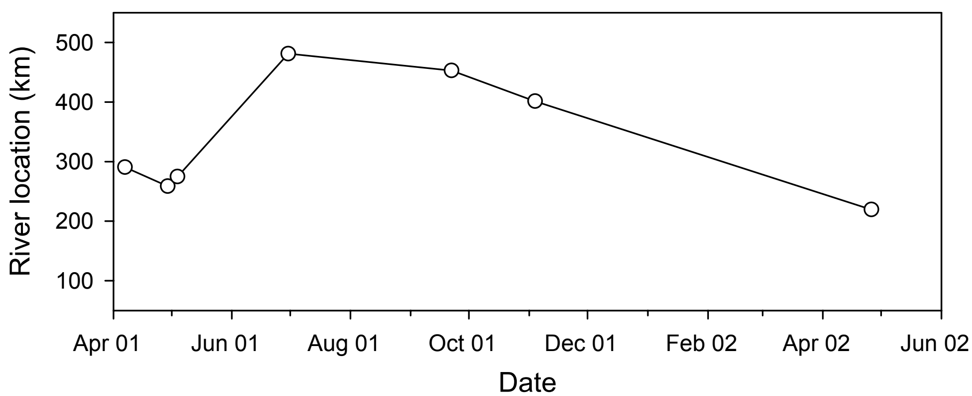


Figure 31. Movements of sauger 48.132 (N=8) during 2001 and 2002 in the Yellowstone River, Montana.

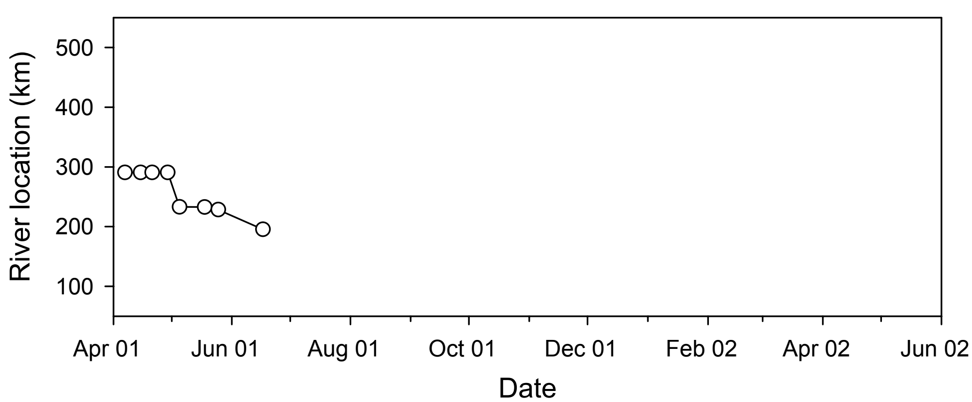


Figure 32. Movements of sauger 48.151 (N=8) during 2001 and 2002 in the Yellowstone River, Montana.

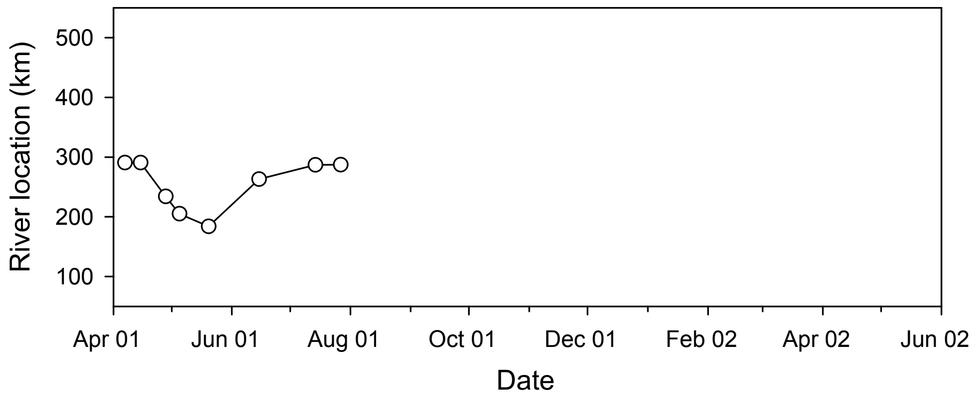


Figure 33. Movements of sauger 48.012 (N=8) during 2001 and 2002 in the Yellowstone River, Montana.

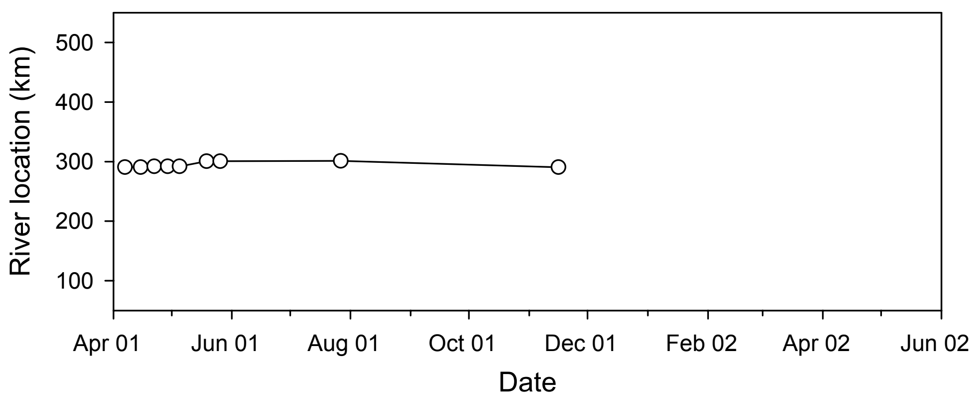


Figure 34. Movements of sauger 48.393 (N=8) during 2001 and 2002 in the Yellowstone River, Montana.

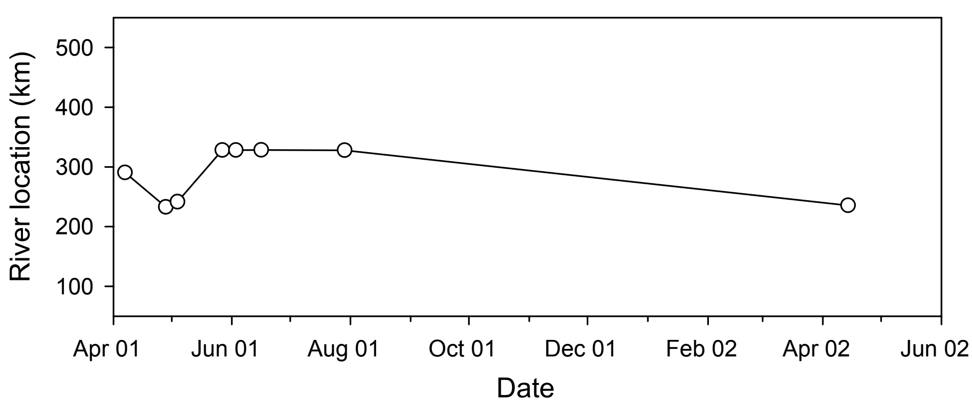


Figure 35. Movements of sauger 48.492 (N=9) during 2001 and 2002 in the Yellowstone River, Montana.

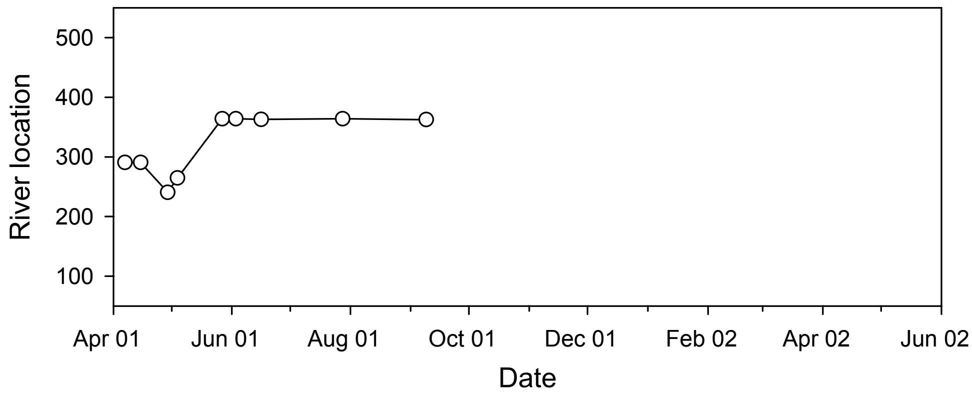


Figure 36. Movements of sauger 48.092 (N=9) during 2001 and 2002 in the Yellowstone River, Montana.

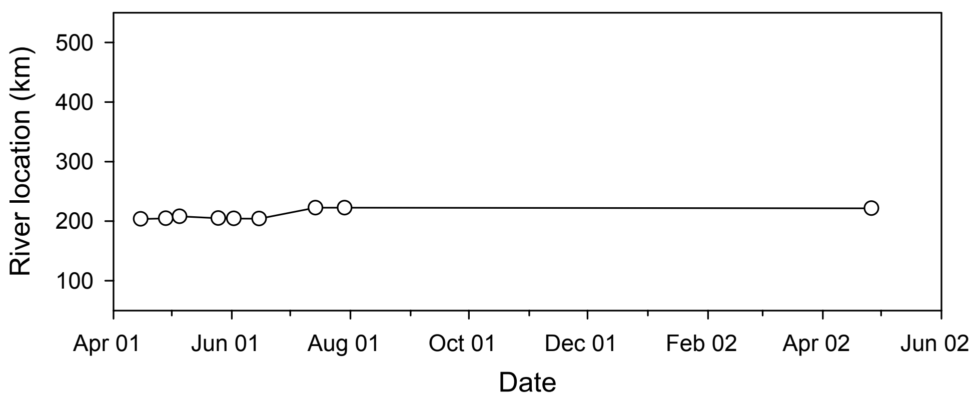


Figure 37. Movements of sauger 48.531 (N=9) during 2001 and 2002 in the Yellowstone River, Montana.

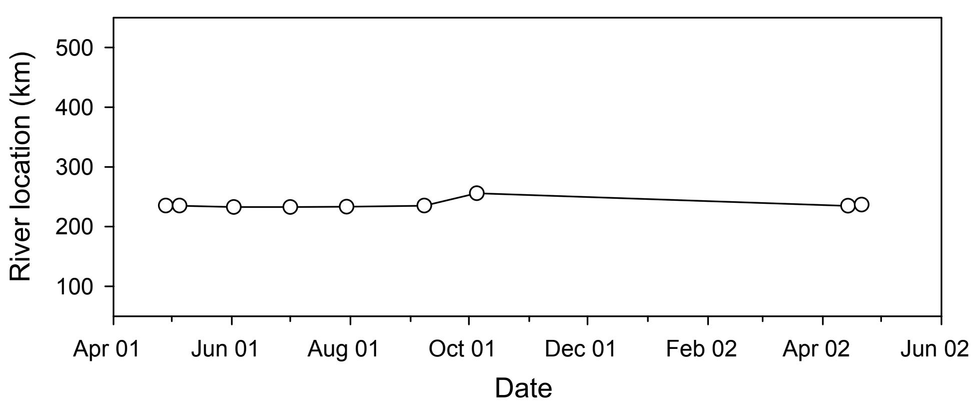


Figure 38. Movements of sauger 48.191 (N=10) during 2001 and 2002 in the Yellowstone River, Montana.

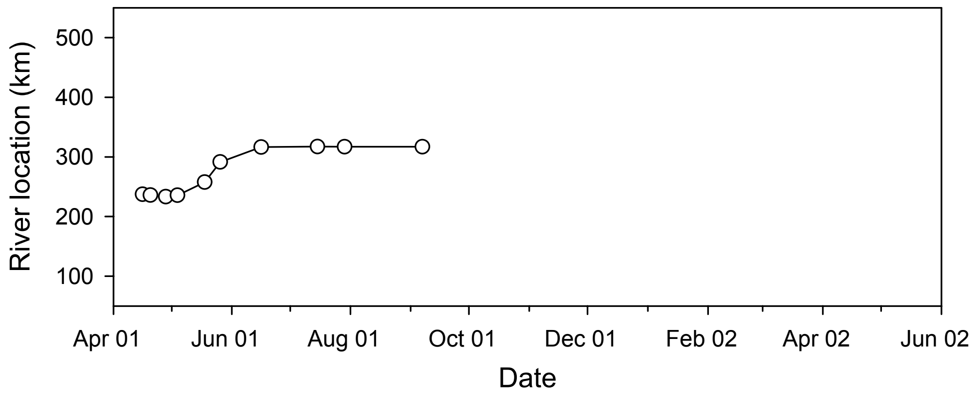


Figure 39. Movements of sauger 48.172 (N=10) during 2001 and 2002 in the Yellowstone River, Montana.

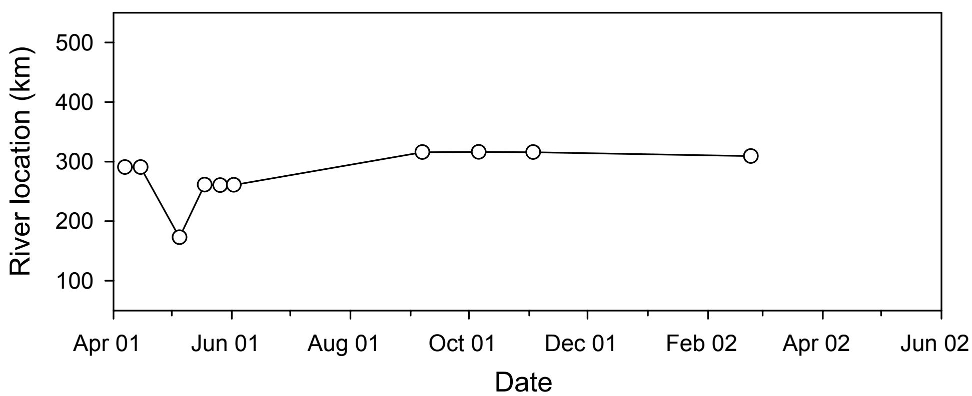


Figure 40. Movements of sauger 48.450 (N=10) during 2001 and 2002 in the Yellowstone River, Montana.

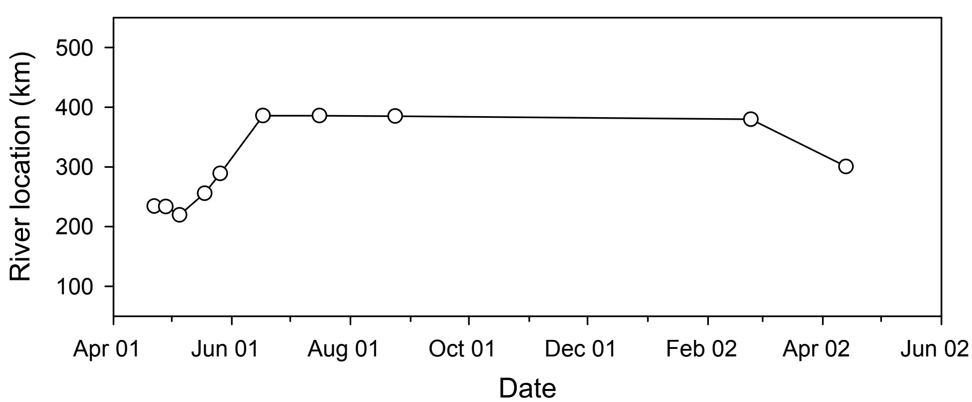


Figure 41. Movements of sauger 48.511 (N=14) during 2001 and 2002 in the Yellowstone River, Montana.

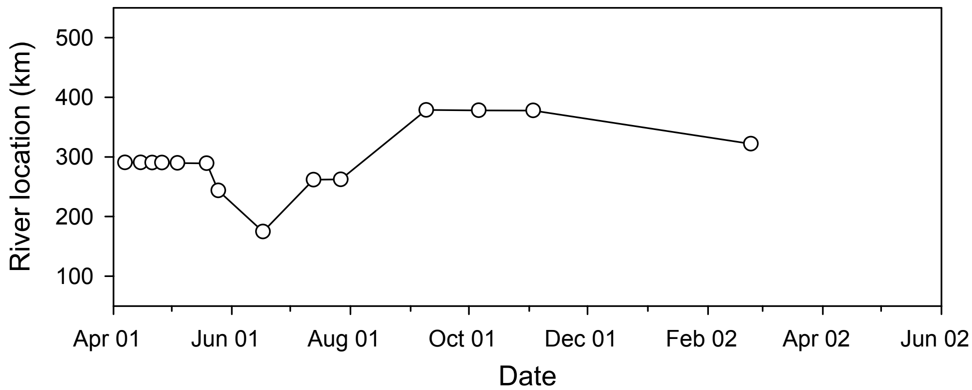


Figure 42. Movements of sauger 48.322 (N=15) during 2001 and 2002 in the Yellowstone River, Montana.

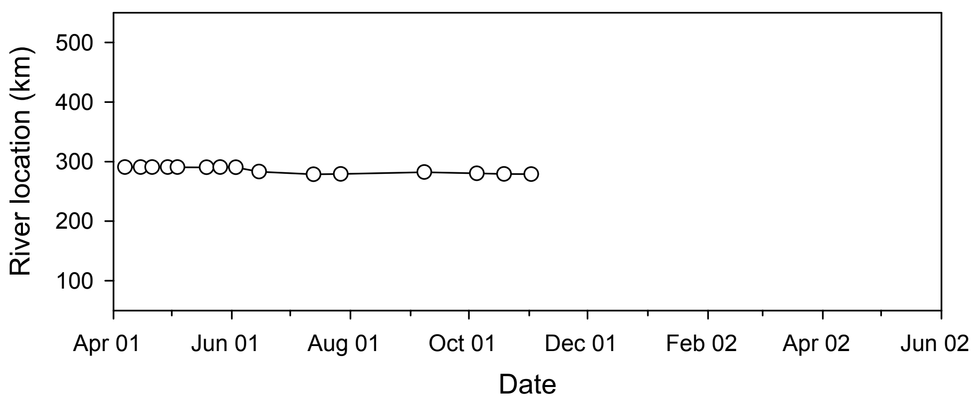


Figure 43. Movements of sauger 48.472 (N=15) during 2001 and 2002 in the Yellowstone River, Montana.

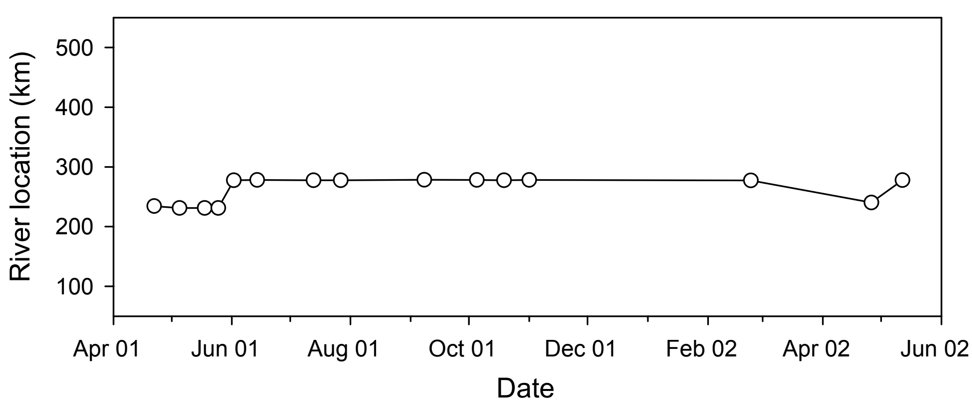


Figure 44. Movements of sauger 48.572 (N=3) during 2001 to 2003 in the Yellowstone River, Montana.

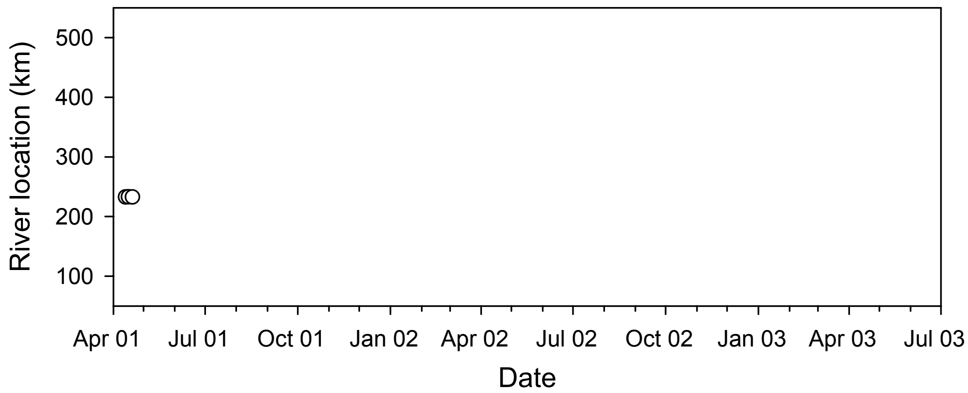


Figure 45. Movements of sauger 48.641 (N=5) during 2001 to 2003 in the Yellowstone River, Montana.

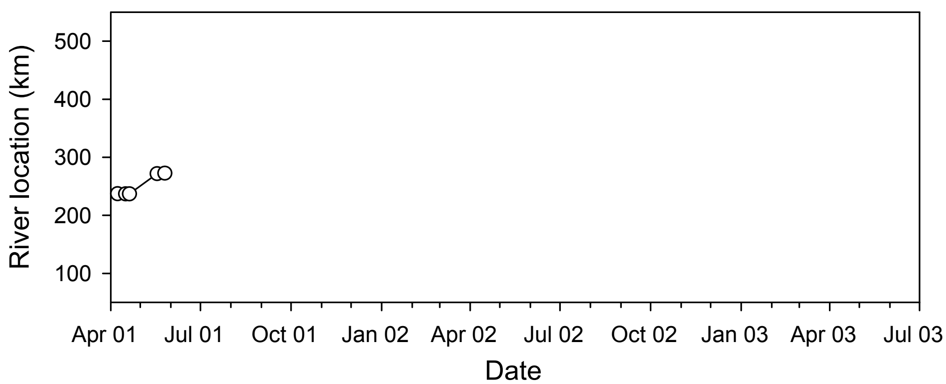


Figure 46. Movements of sauger 48.551 (N=9) during 2001 to 2003 in the Yellowstone River, Montana.

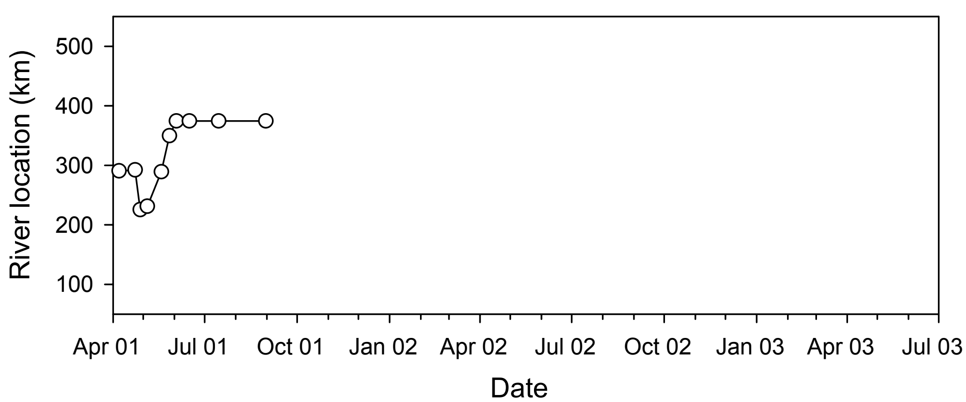


Figure 47. Movements of sauger 48.620 (N=15) during 2001 to 2003 in the Yellowstone River, Montana.

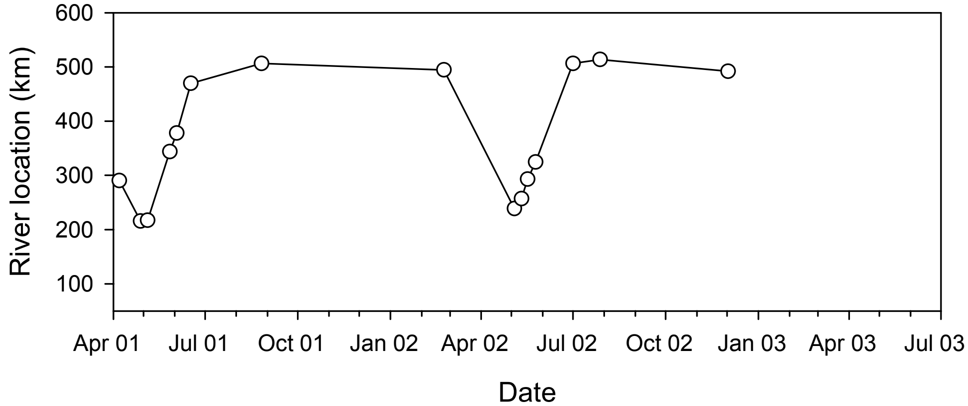


Figure 48. Movements of sauger 48.591 (N=32) during 2001 to 2003 in the Yellowstone River, Montana.

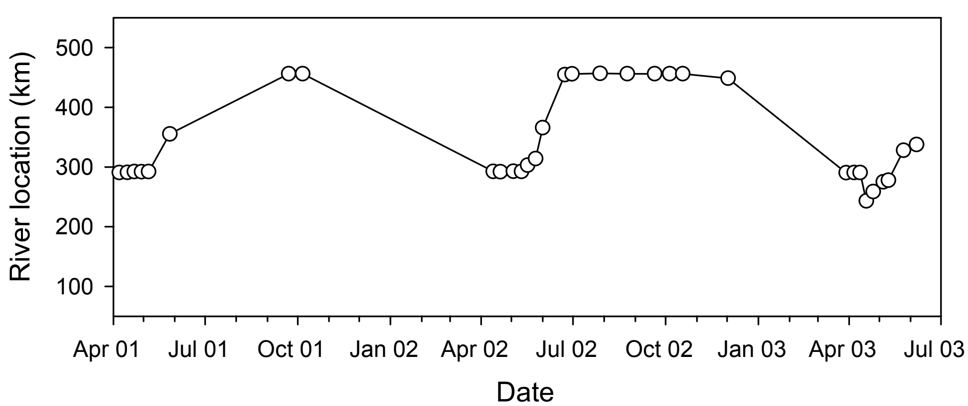


Figure 49. Movements of sauger 48.661 (N=42) during 2001 to 2003 in the Yellowstone River, Montana.

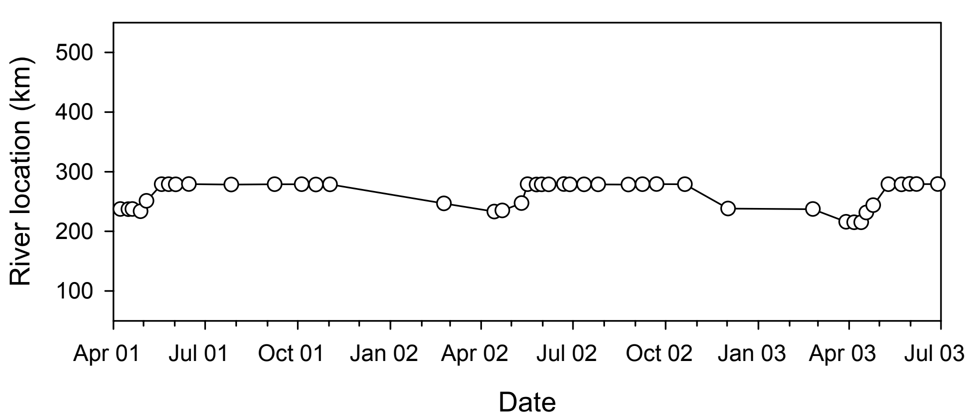


Figure 50. Movements of sauger 48.341-10 (N=2) during 2002 and 2003 in the Yellowstone River, Montana.

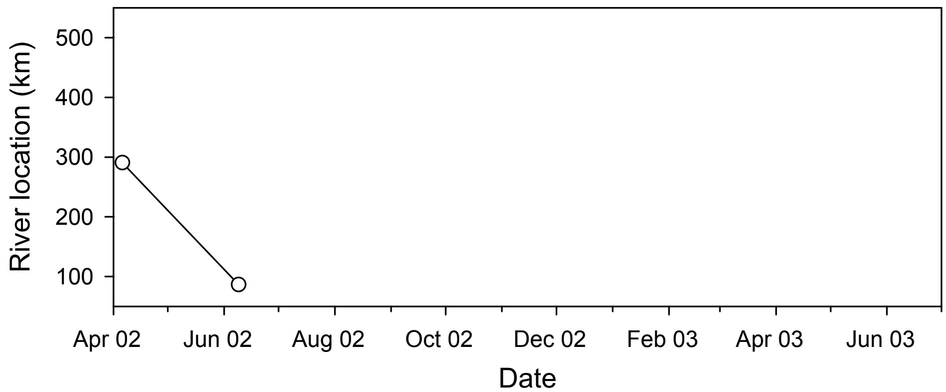


Figure 51. Movements of sauger 48.501-5 (N=4) during 2002 and 2003 in the Yellowstone River, Montana.

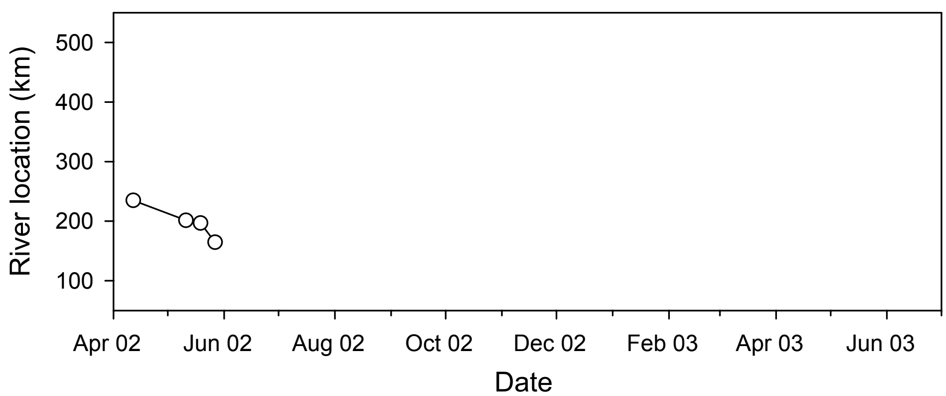


Figure 52. Movements of sauger 48.251-10 (N=5) during 2002 and 2003 in the Yellowstone River, Montana.

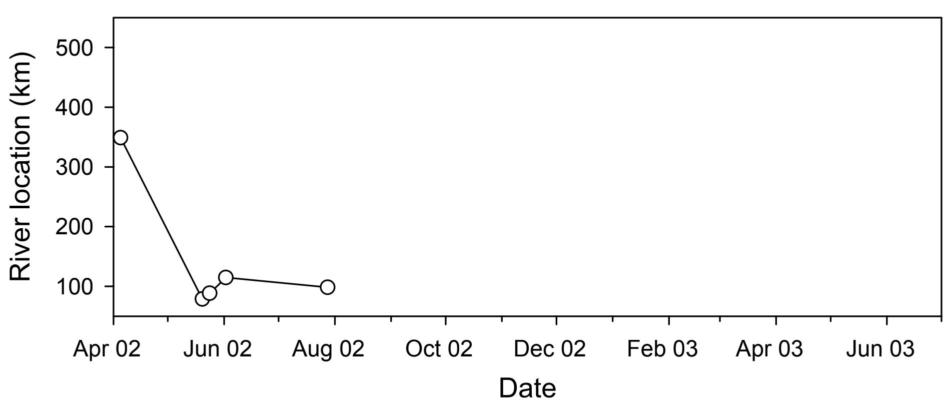


Figure 53. Movements of sauger 48.572b (N=6) during 2002 and 2003 in the Yellowstone River, Montana.

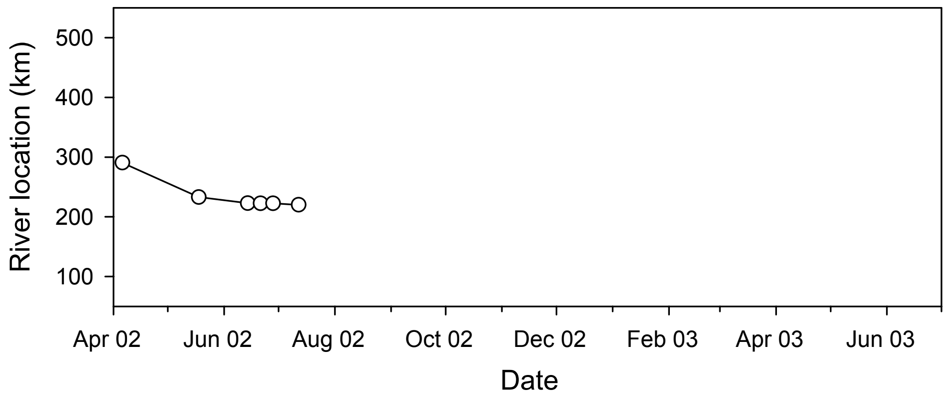


Figure 54. Movements of sauger 48.221-10 (N=7) during 2002 and 2003 in the Yellowstone River, Montana.

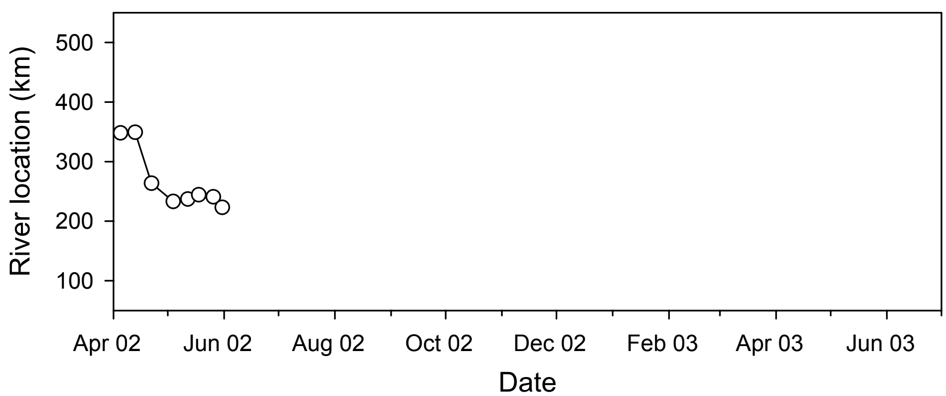


Figure 55. Movements of sauger 48.251 (N=7) during 2002 and 2003 in the Yellowstone River, Montana.

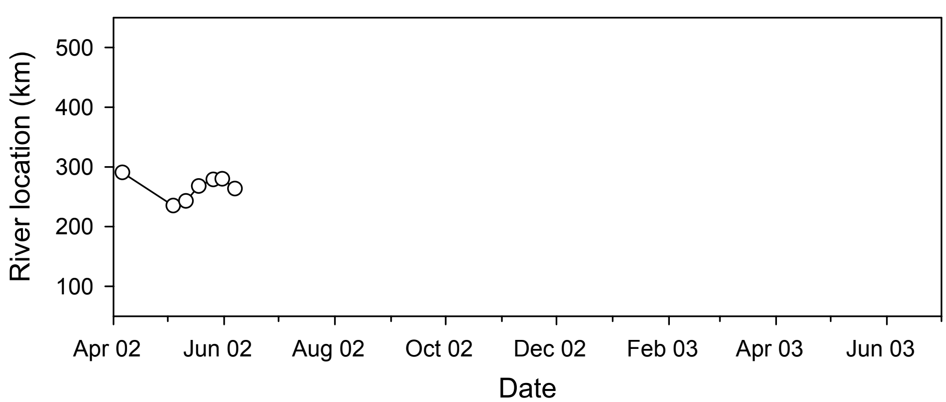


Figure 56. Movements of sauger 48.211-10 (N=8) during 2002 and 2003 in the Yellowstone River, Montana.

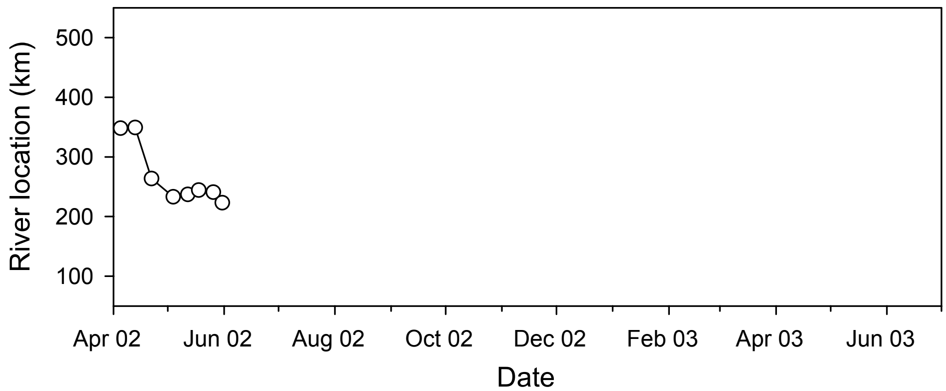


Figure 57. Movements of sauger 48.341 (N=8) during 2002 and 2003 in the Yellowstone River, Montana.

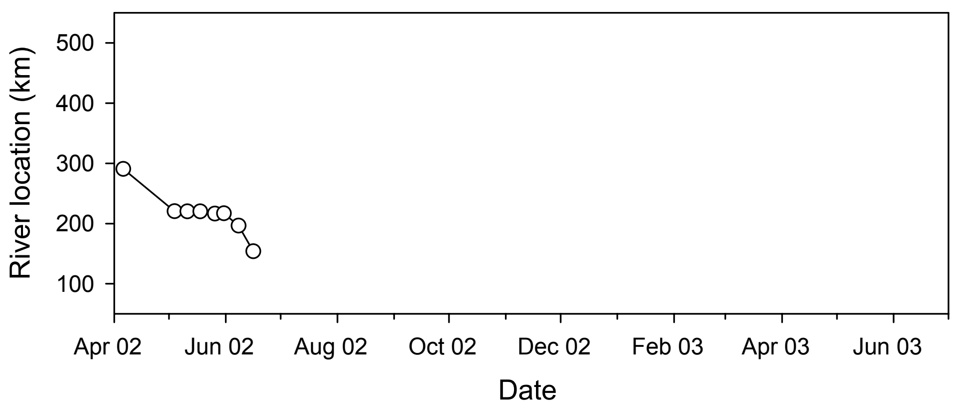


Figure 58. Movements of sauger 48.271-5 (N=9) during 2002 and 2003 in the Yellowstone River, Montana.

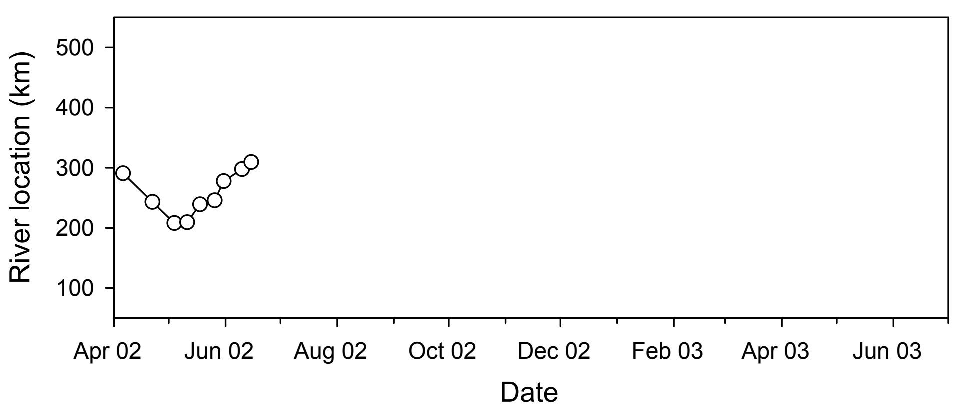


Figure 59. Movements of sauger 48.362-5 (N=9) during 2002 and 2003 in the Yellowstone River, Montana.

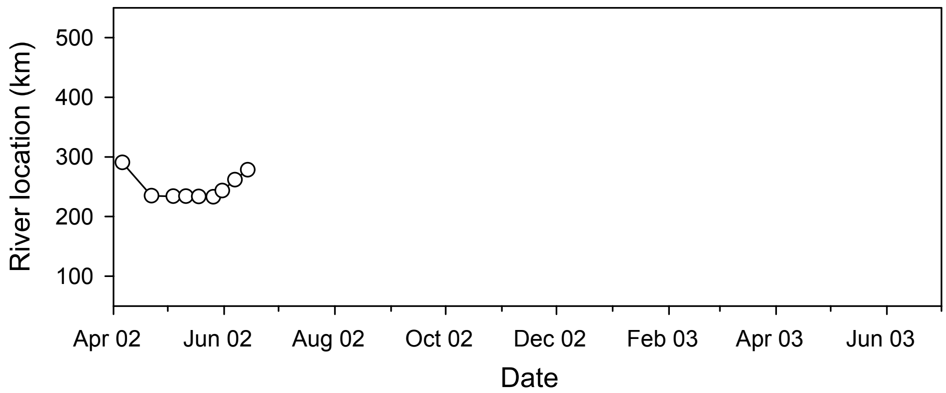


Figure 60. Movements of sauger 48.211 (N=10) during 2002 and 2003 in the Yellowstone River, Montana.

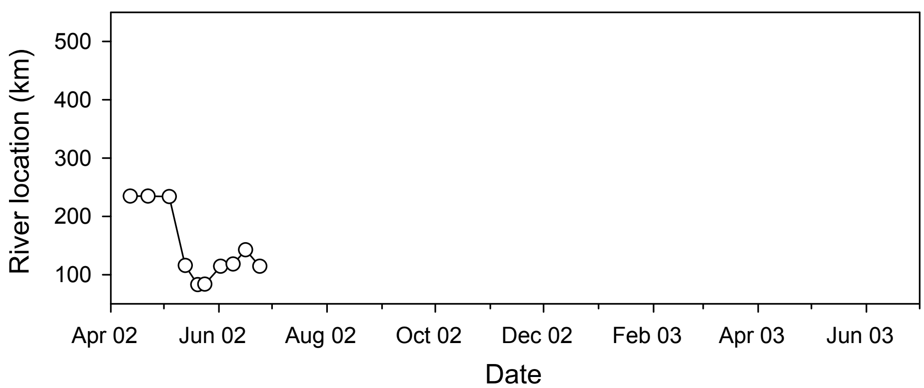


Figure 61. Movements of sauger 48.211-5 (N=13) during 2002 and 2003 in the Yellowstone River, Montana.

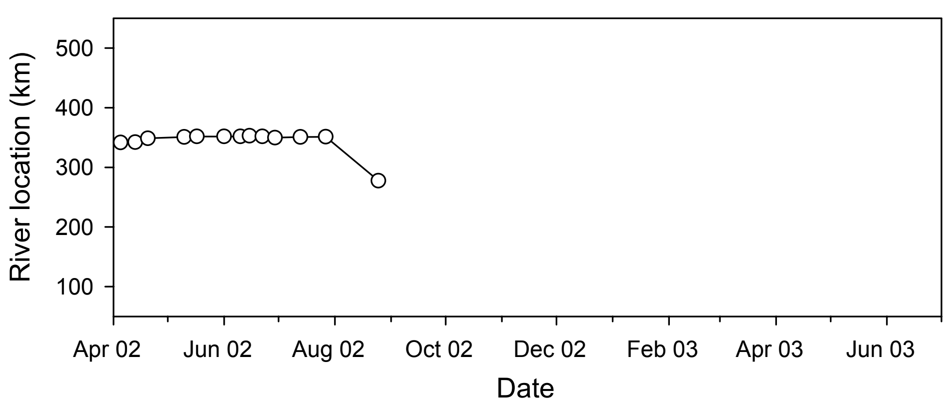


Figure 62. Movements of sauger 48.261-10 (N=13) during 2002 and 2003 in the Yellowstone River, Montana.

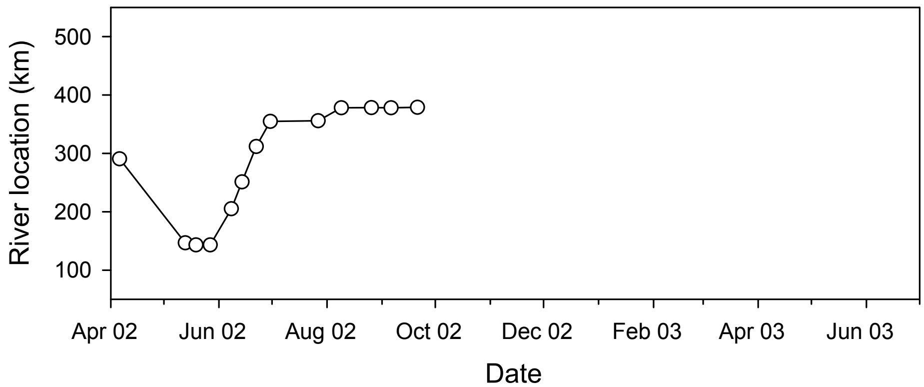


Figure 63. Movements of sauger 48.261-5 (N=13) during 2002 and 2003 in the Yellowstone River, Montana.

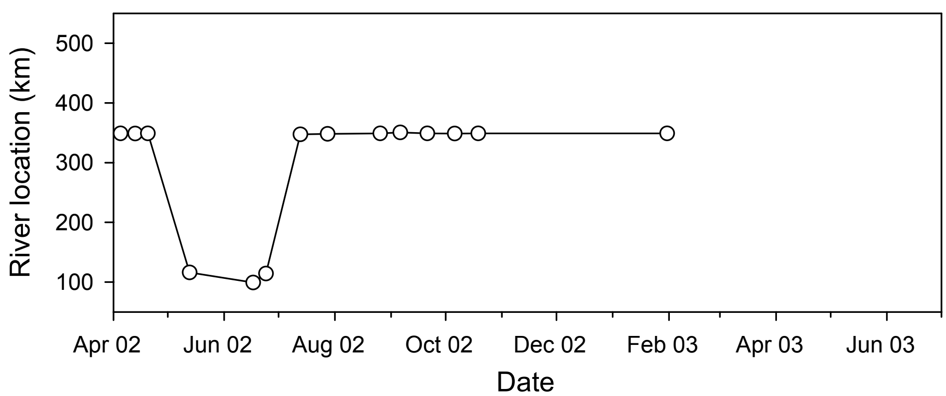


Figure 64. Movements of sauger 48.291-5 (N=14) during 2002 and 2003 in the Yellowstone River, Montana.

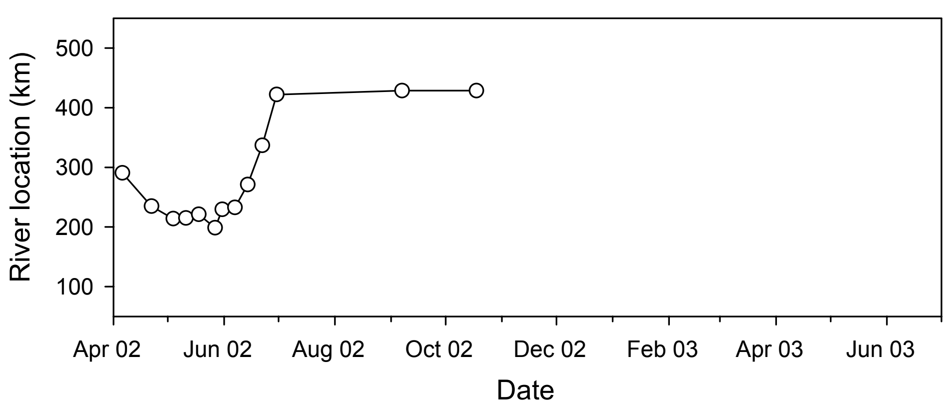


Figure 65. Movements of sauger 48.421 (N=16) during 2002 and 2003 in the Yellowstone River, Montana.

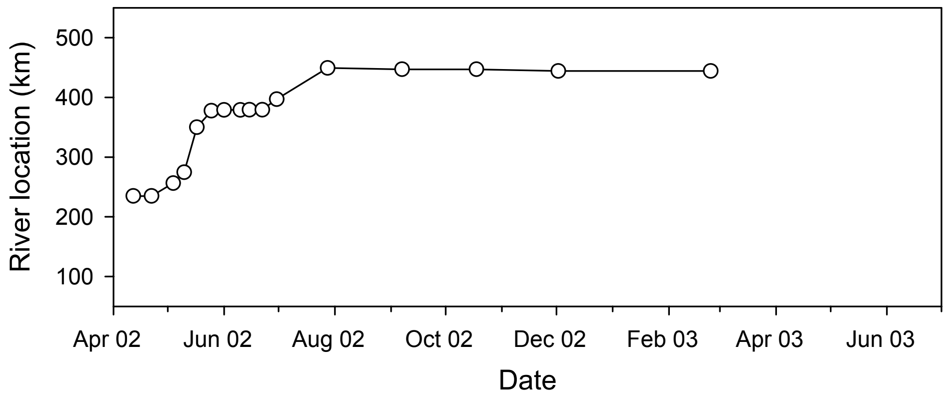


Figure 66. Movements of sauger 48.501-10 (N=16) during 2002 and 2003 in the Yellowstone River, Montana.

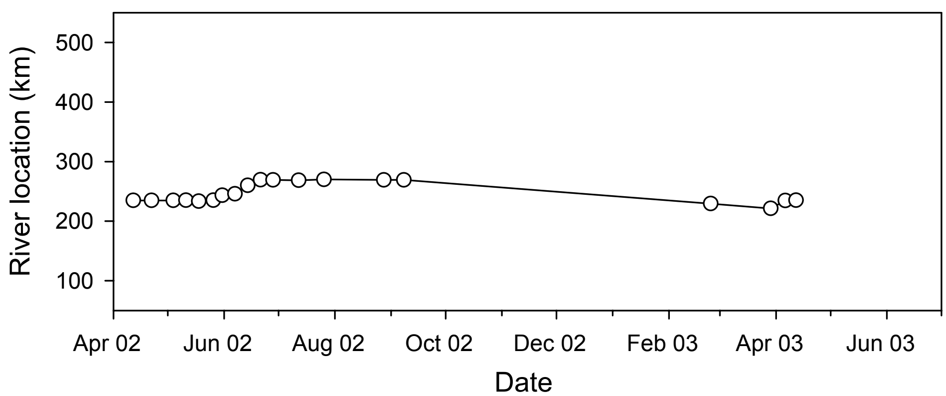


Figure 67. Movements of sauger 48.362-10 (N=17) during 2002 and 2003 in the Yellowstone River, Montana.

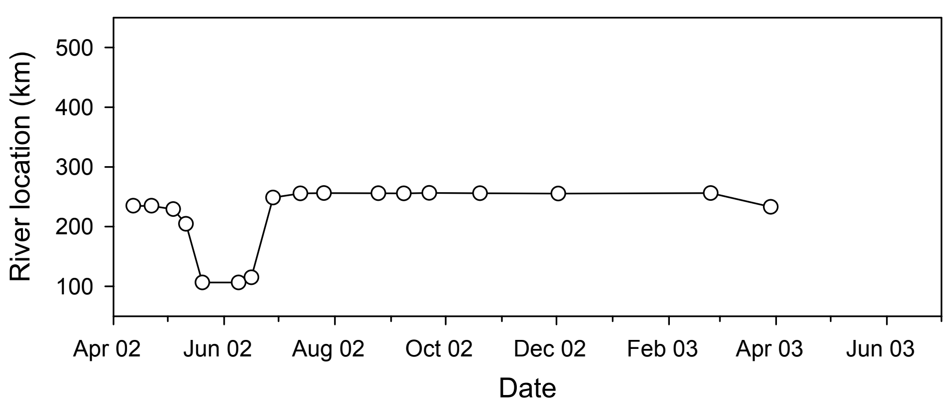


Figure 68. Movements of sauger 48.271-10 (N=18) during 2002 and 2003 in the Yellowstone River, Montana.

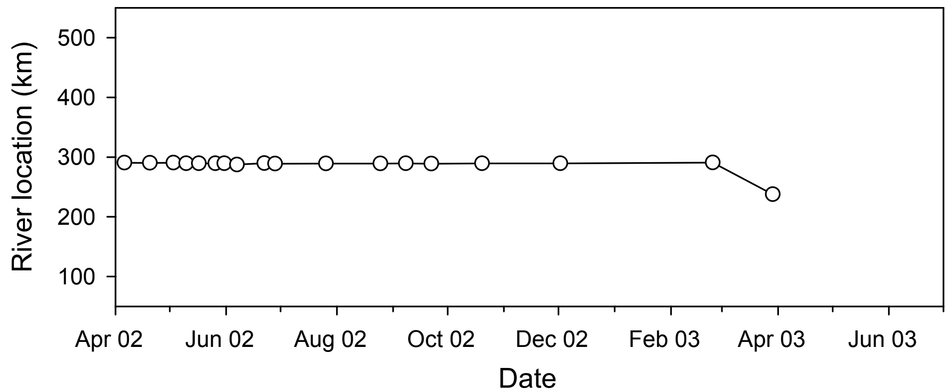


Figure 69. Movements of sauger 48.221-5 (N=22) during 2002 and 2003 in the Yellowstone River, Montana.

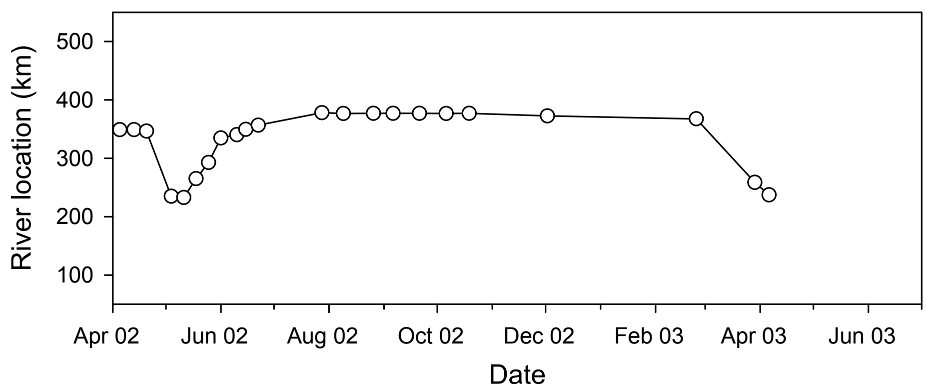


Figure 70. Movements of sauger 48.251-5 (N=23) during 2002 and 2003 in the Yellowstone River, Montana.

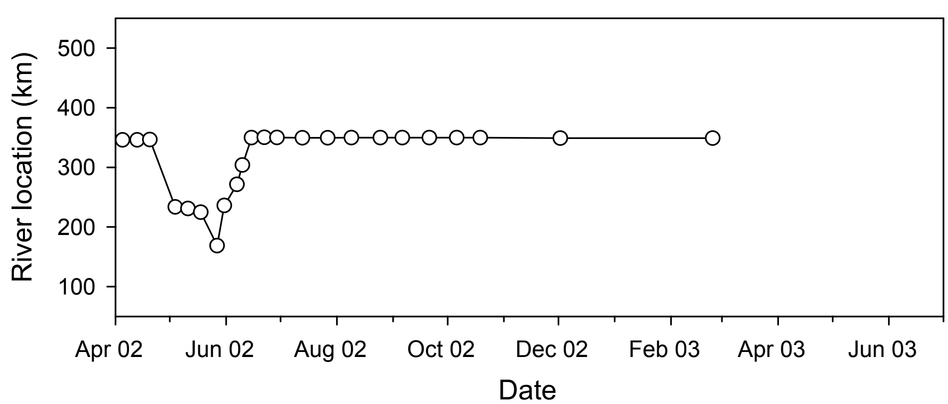


Figure 71. Movements of sauger 48.291-10 (N=23) during 2002 and 2003 in the Yellowstone River, Montana.

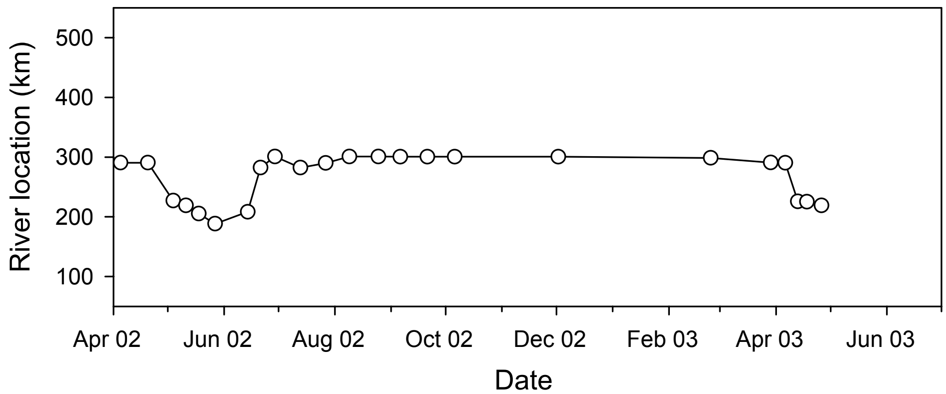


Figure 72. Movements of sauger 48.341-5 (N=23) during 2002 and 2003 in the Yellowstone River, Montana.

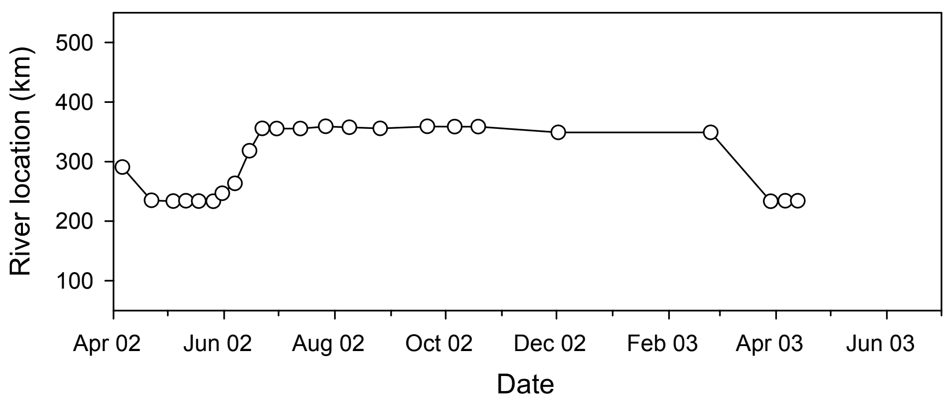


Figure 73. Movements of sauger 48.421-10 (N=23) during 2002 and 2003 in the Yellowstone River, Montana.

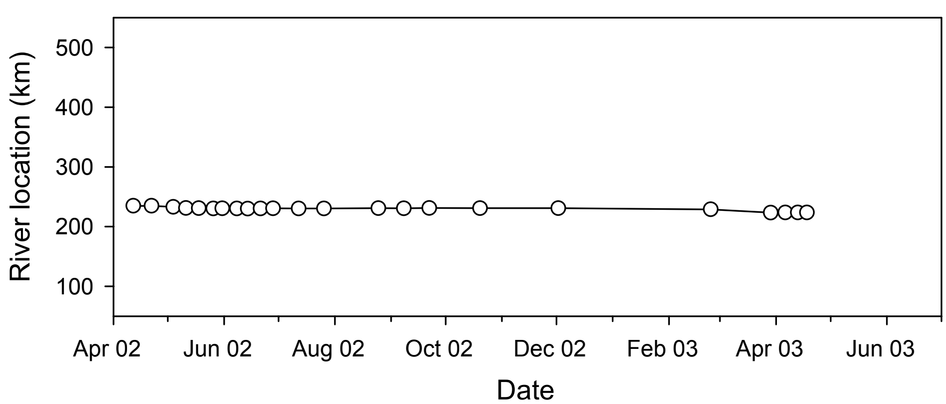


Figure 74. Movements of sauger 48.421-5 (N=24) during 2002 and 2003 in the Yellowstone River, Montana.

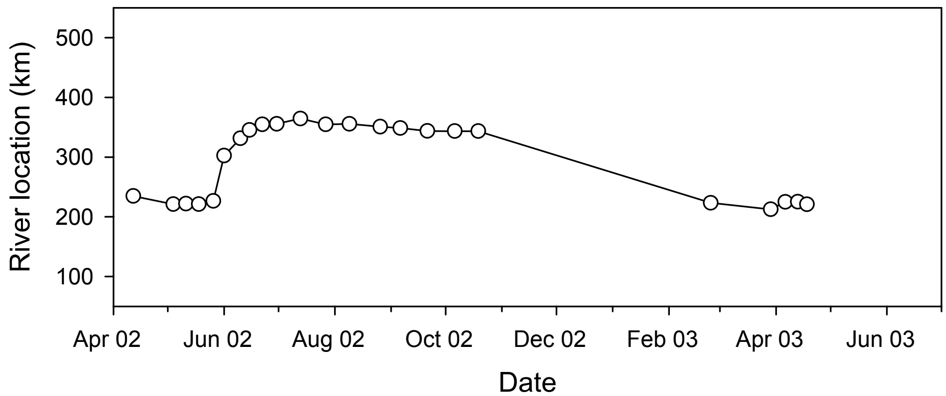


Figure 75. Movements of sauger 48.291 (N=25) during 2002 and 2003 in the Yellowstone River, Montana.

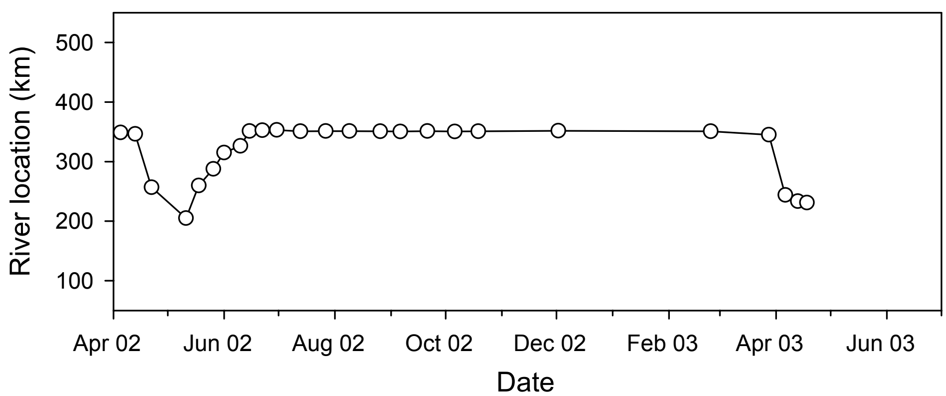


Figure 76. Movements of sauger 48.551b (N=25) during 2002 and 2003 in the Yellowstone River, Montana.

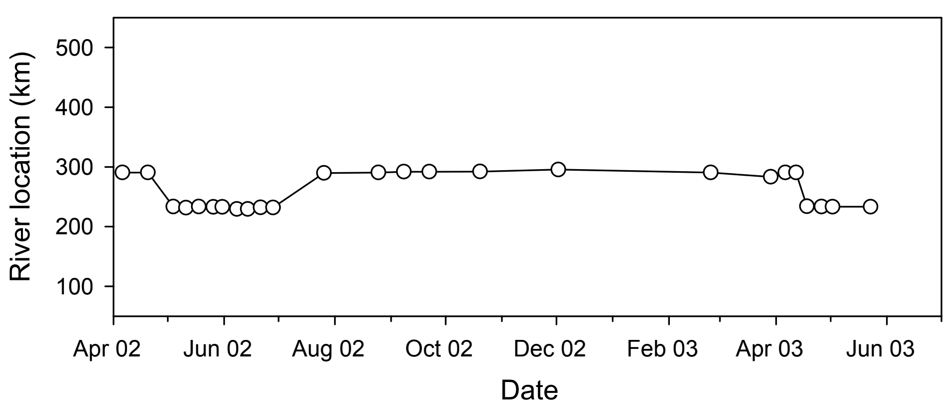


Figure 77. Movements of sauger 48.501 (N=30) during 2002 and 2003 in the Yellowstone River, Montana.

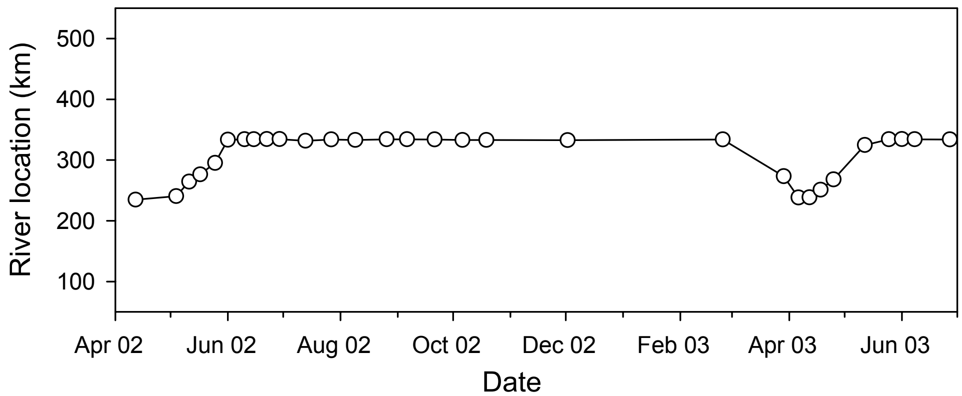


Figure 78. Movements of sauger 48.261 (N=31) during 2002 and 2003 in the Yellowstone River, Montana.

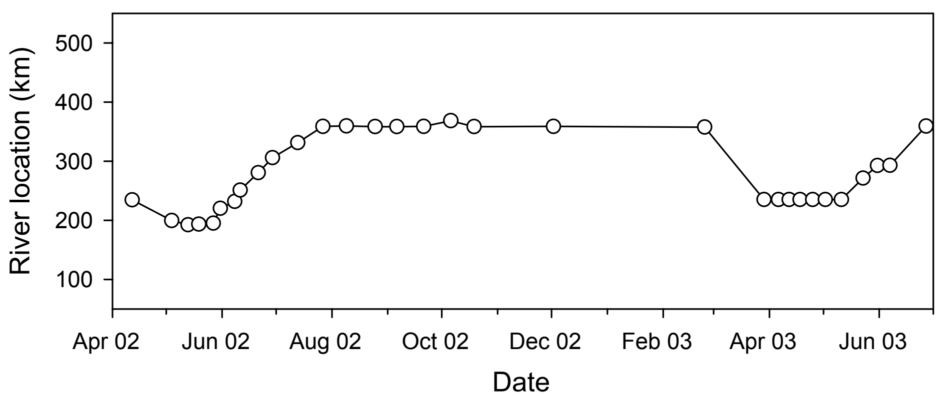


Figure 79. Movements of sauger 48.221 (N=33) during 2002 and 2003 in the Yellowstone River, Montana.

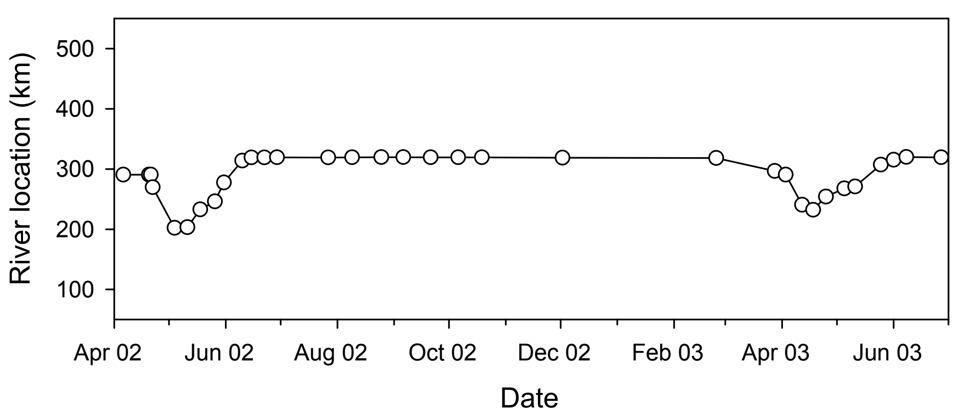


Figure 80. Movements of sauger 48.691 (N=2) during 2003 in the Yellowstone River, Montana.

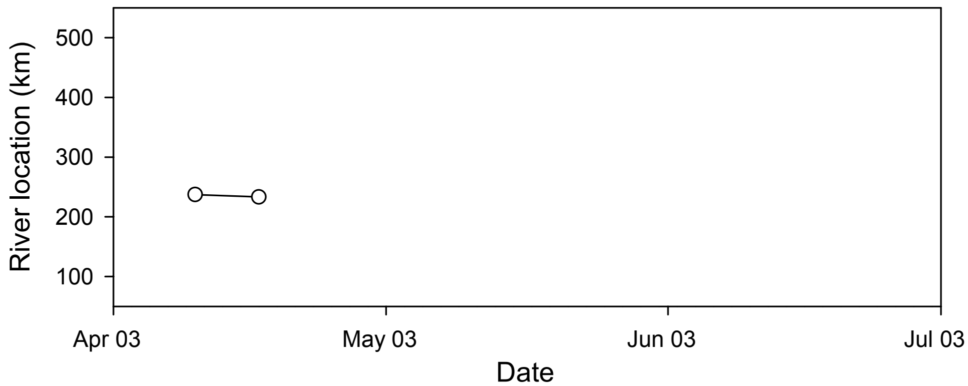


Figure 81. Movements of sauger 48.861 (N=3) during 2003 in the Yellowstone River, Montana.

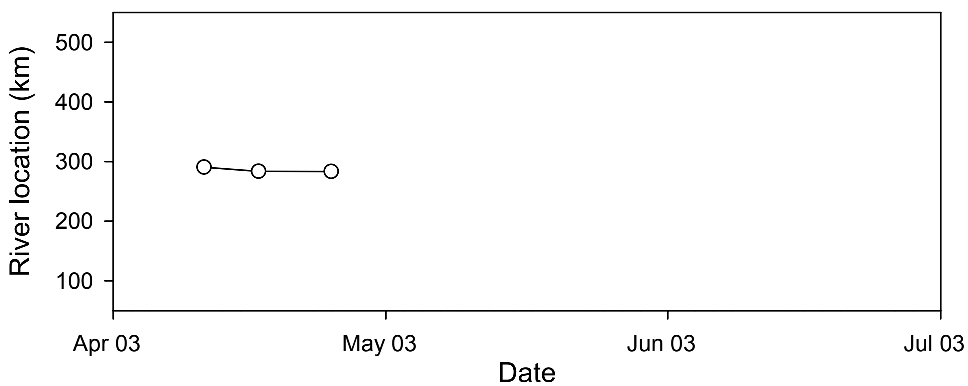


Figure 82. Movements of sauger 48.941 (N=3) during 2003 in the Yellowstone River, Montana.

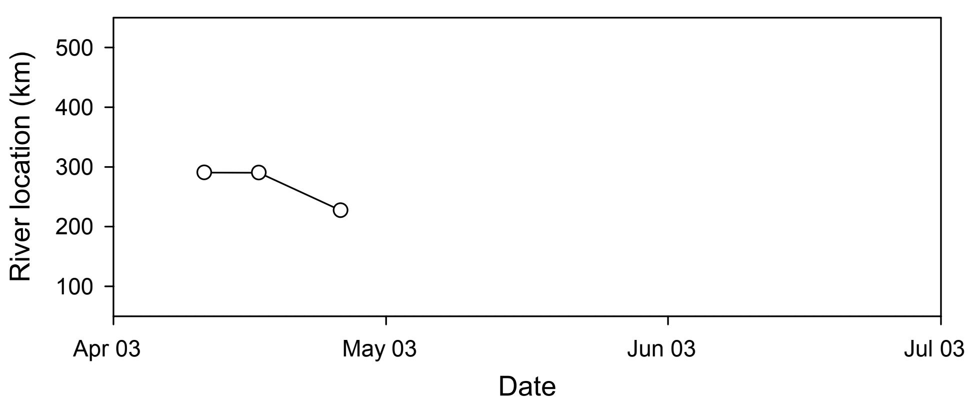


Figure 83. Movements of sauger 48.931 (N=3) during 2003 in the Yellowstone River, Montana.

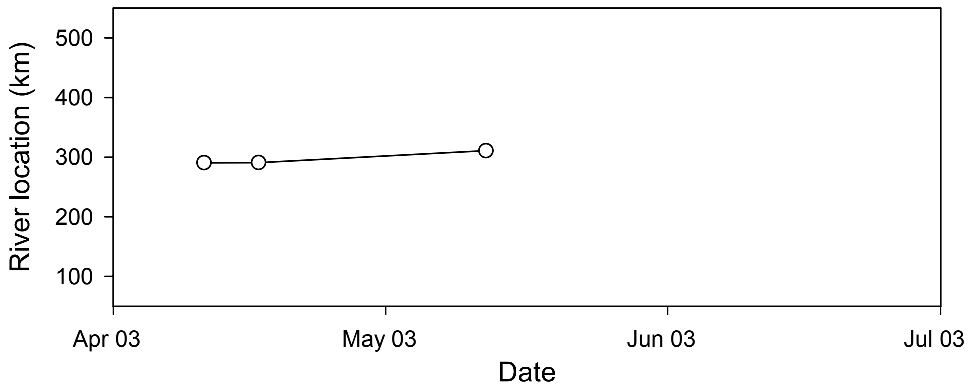


Figure 84. Movements of sauger 48.881 (N=6) during 2003 in the Yellowstone River, Montana.

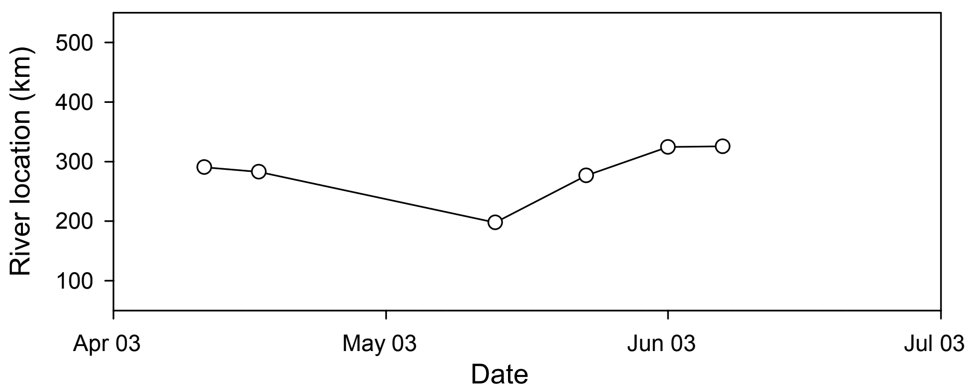


Figure 85. Movements of sauger 48.701 (N=6) during 2003 in the Yellowstone River, Montana.

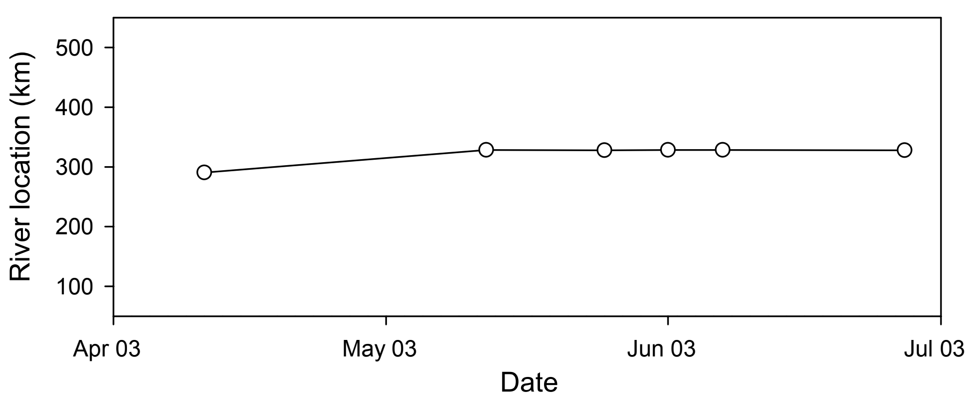


Figure 86. Movements of sauger 48.741 (N=7) during 2003 in the Yellowstone River, Montana.

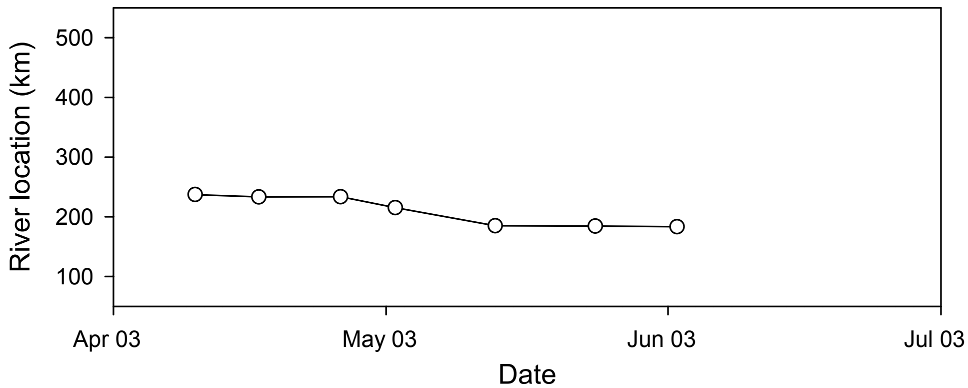


Figure 87. Movements of sauger 48.981 (N=7) during 2003 in the Yellowstone River, Montana.

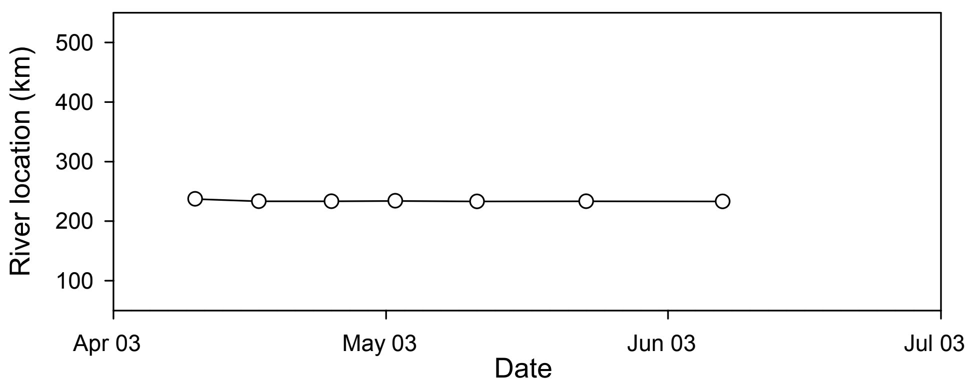


Figure 88. Movements of sauger 48.971 (N=8) during 2003 in the Yellowstone River, Montana.

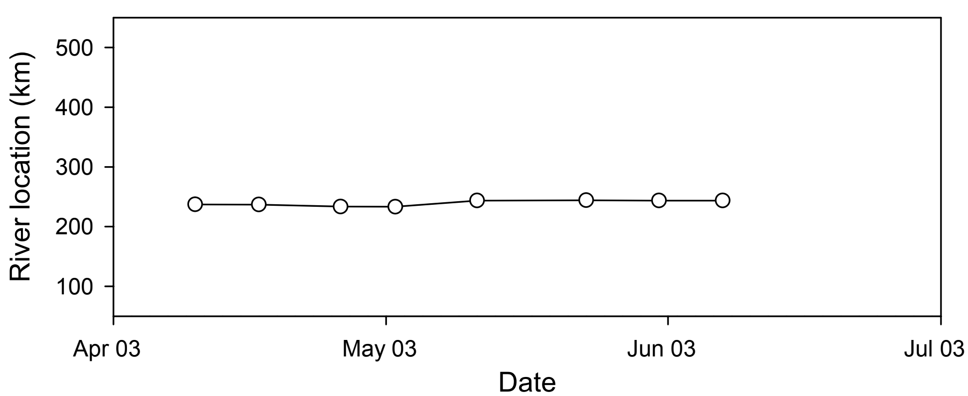


Figure 89. Movements of sauger 48.711 (N=8) during 2003 in the Yellowstone River, Montana.

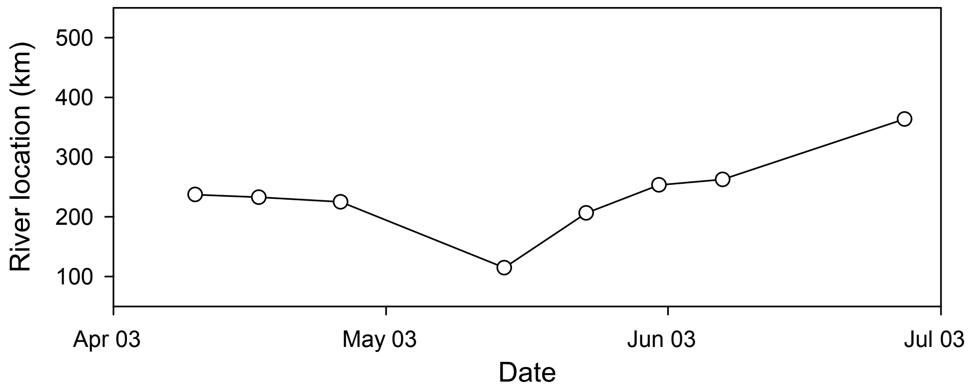


Figure 90. Movements of sauger 48.731 (N=8) during 2003 in the Yellowstone River, Montana.

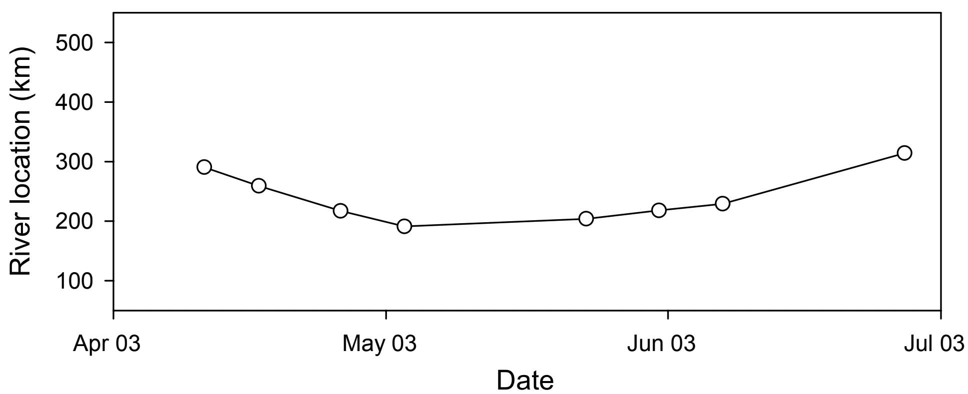


Figure 91. Movements of sauger 48.791 (N=8) during 2003 in the Yellowstone River, Montana.

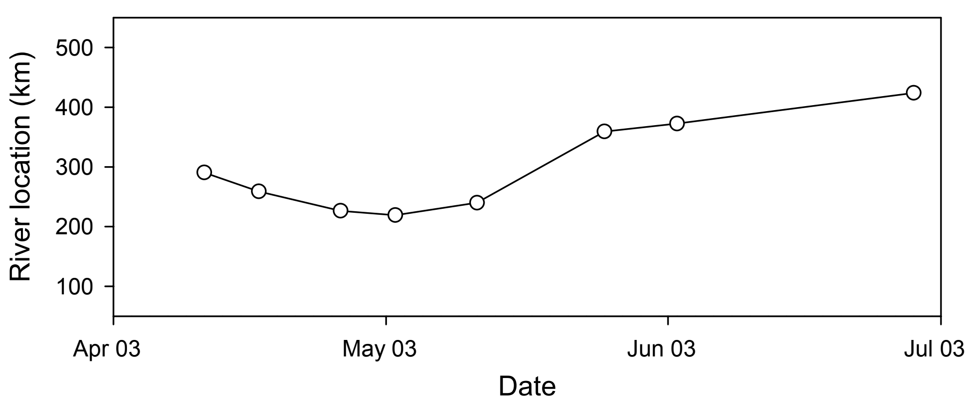


Figure 92. Movements of sauger 48.991 (N=8) during 2003 in the Yellowstone River, Montana.

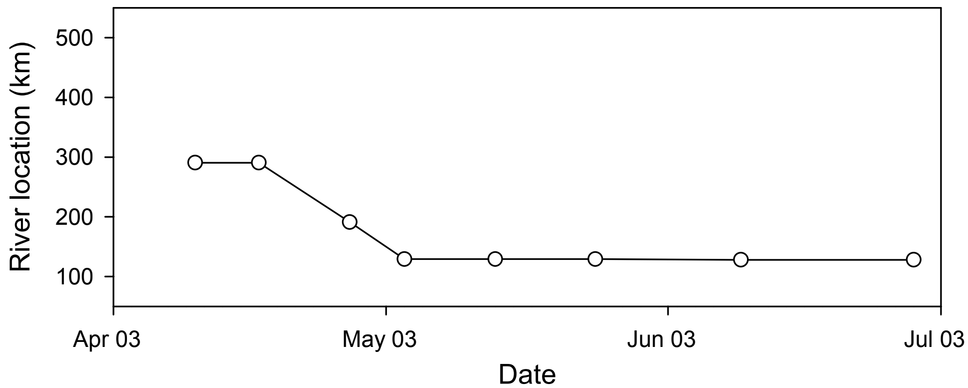


Figure 93. Movements of sauger 48.851 (N=9) during 2003 in the Yellowstone River, Montana.

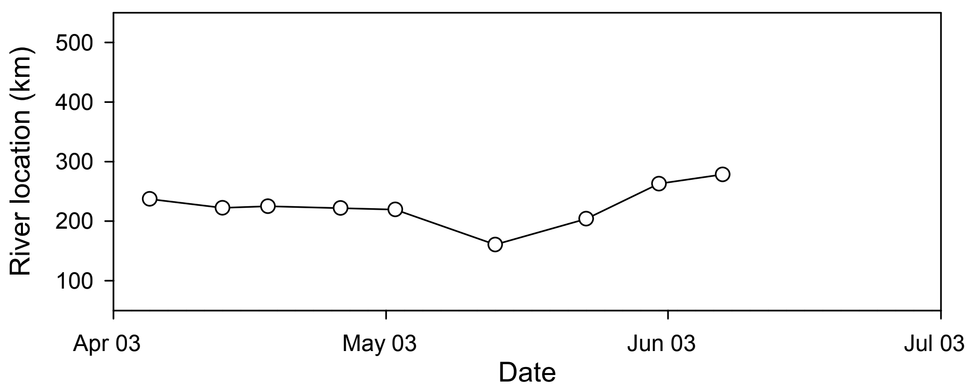


Figure 94. Movements of sauger 48.871 (N=9) during 2003 in the Yellowstone River, Montana.

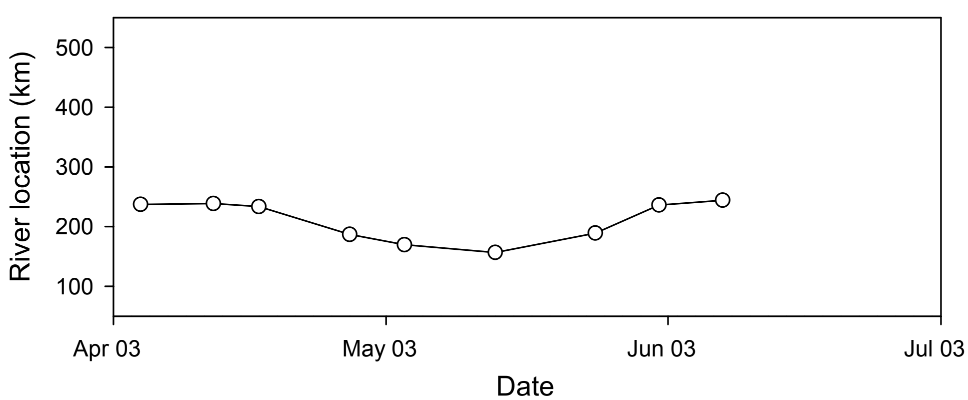


Figure 95. Movements of sauger 48.957 (N=9) during 2003 in the Yellowstone River, Montana.

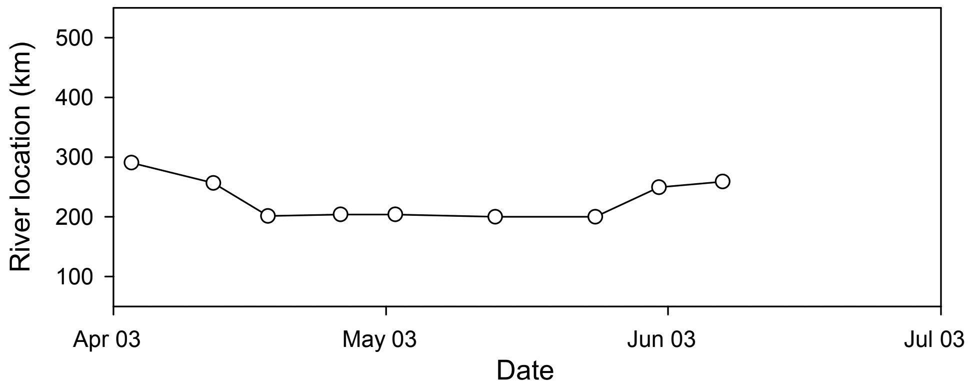


Figure 96. Movements of sauger 48.752 (N=9) during 2003 in the Yellowstone River, Montana.

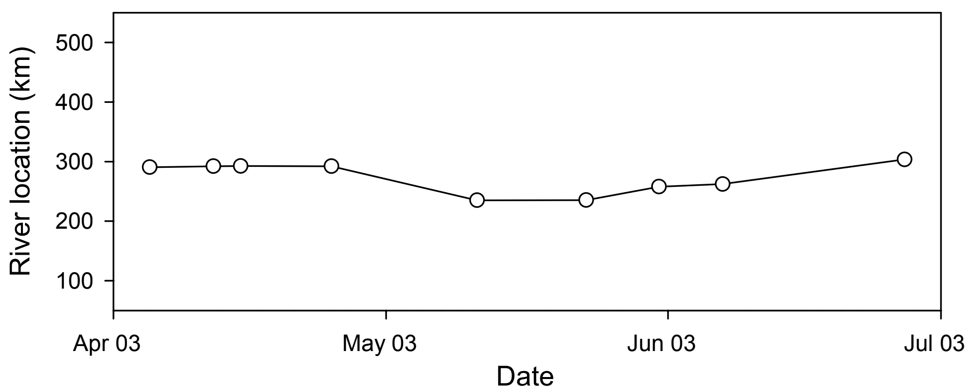


Figure 97. Movements of sauger 48.771 (N=9) during 2003 in the Yellowstone River, Montana.

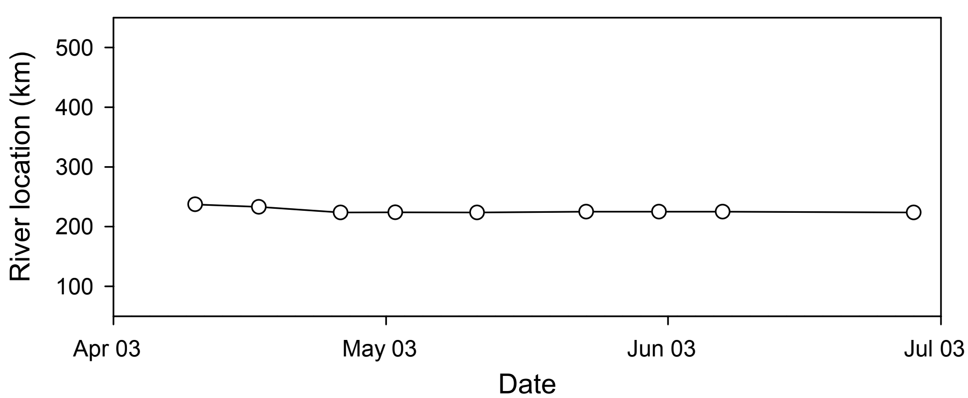


Figure 98. Movements of sauger 48.801 (N=9) during 2003 in the Yellowstone River, Montana.

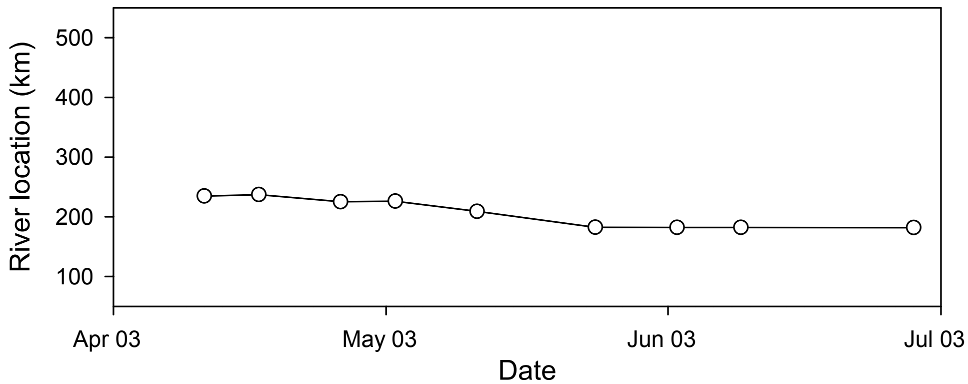


Figure 99. Movements of sauger 48.811 (N=9) during 2003 in the Yellowstone River, Montana.

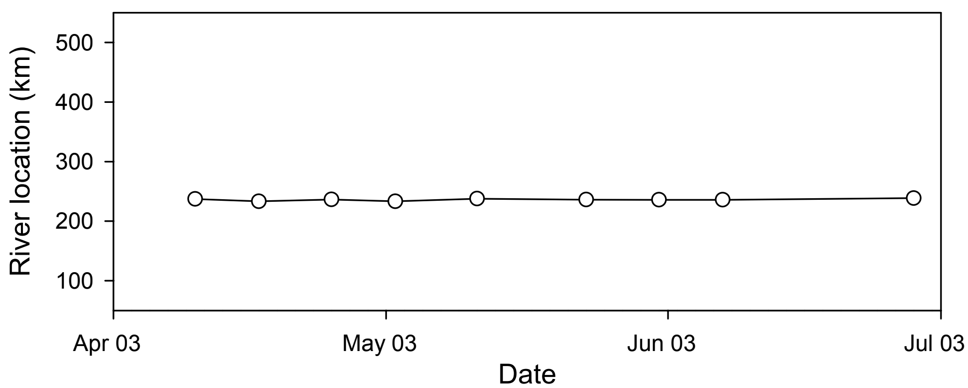


Figure 100. Movements of sauger 48.891 (N=9) during 2003 in the Yellowstone River, Montana.

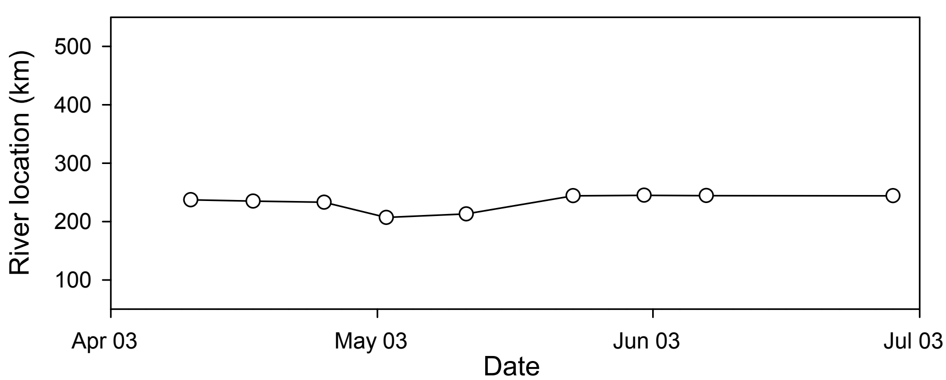


Figure 101. Movements of sauger 48.912 (N=9) during 2003 in the Yellowstone River, Montana.

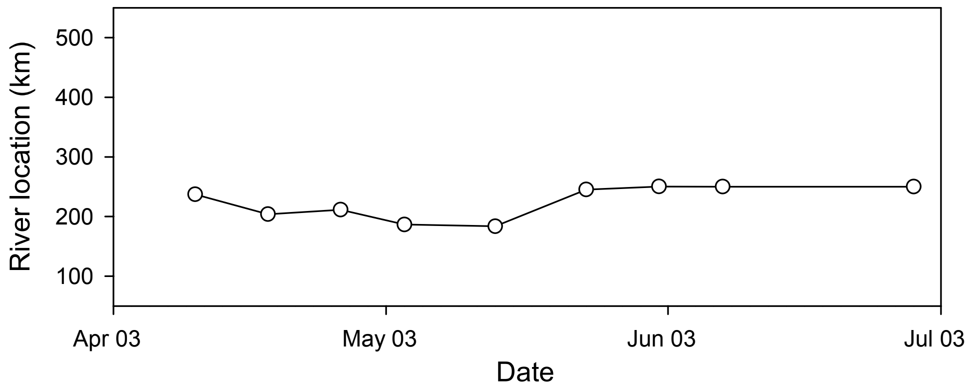


Figure 102. Movements of sauger 48.671 (N=10) during 2003 in the Yellowstone River, Montana.

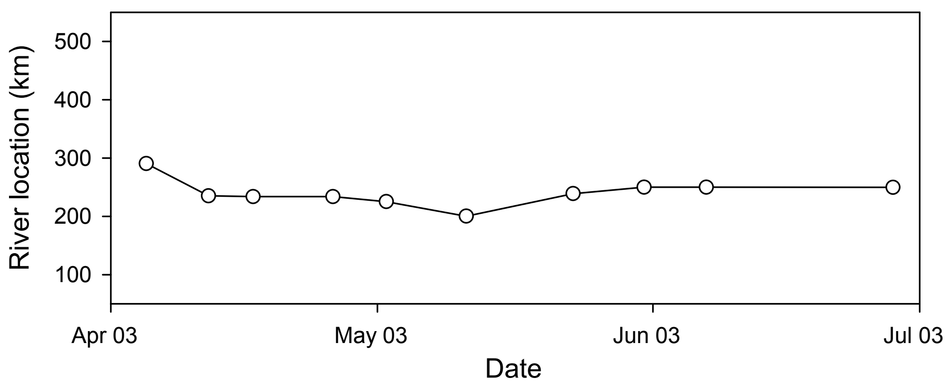


Figure 103. Movements of sauger 48.681 (N=10) during 2003 in the Yellowstone River, Montana.

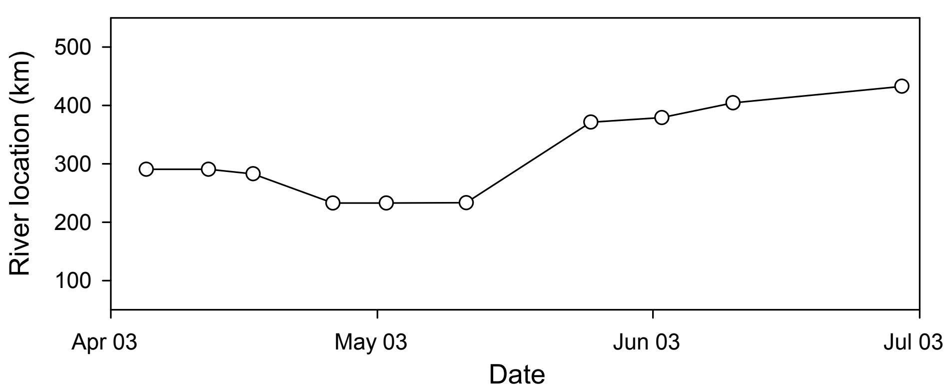


Figure 104. Movements of sauger 48.761 (N=10) during 2003 in the Yellowstone River, Montana.

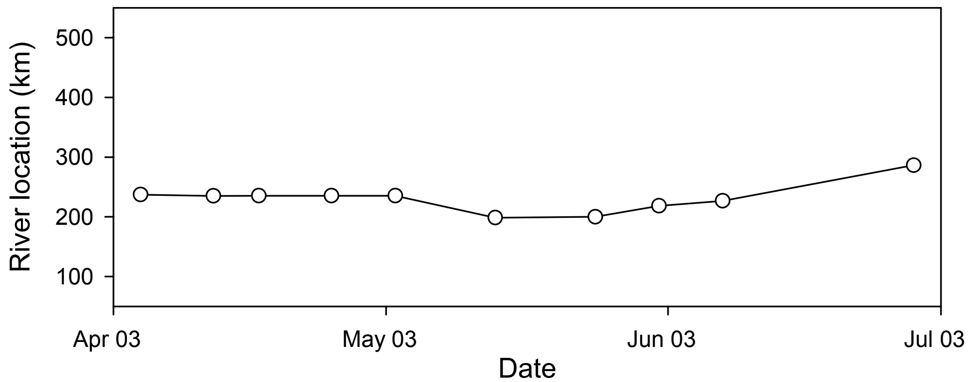


Figure 105. Movements of sauger 48.821 (N=10) during 2003 in the Yellowstone River, Montana.

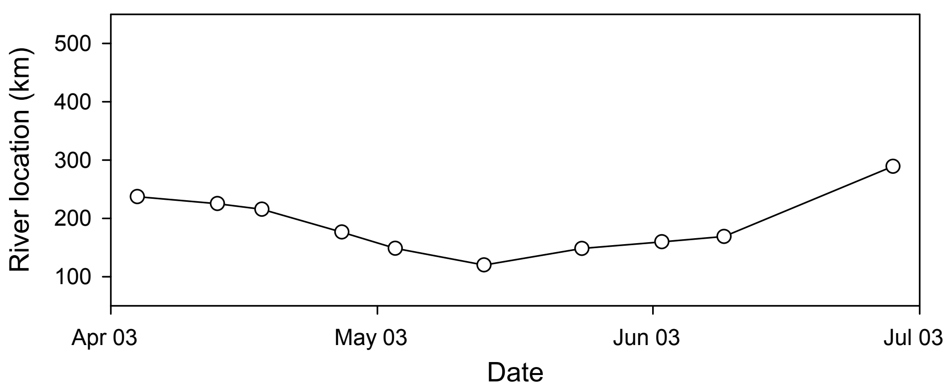


Figure 106. Movements of sauger 48.831 (N=10) during 2003 in the Yellowstone River, Montana.

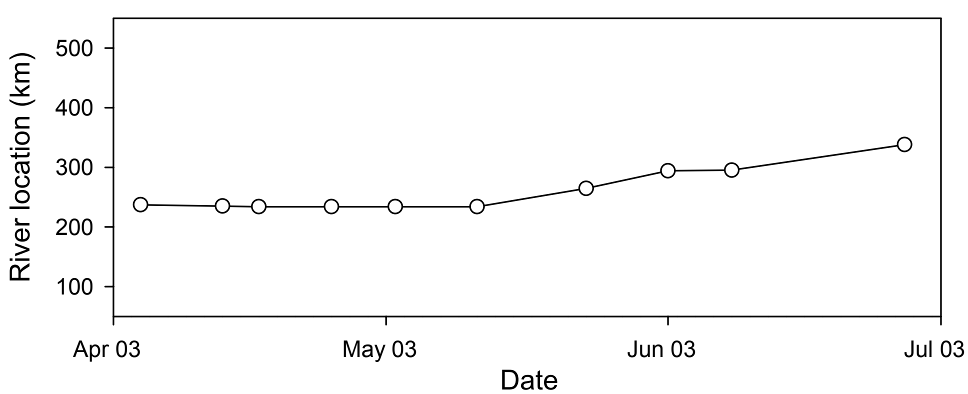


Figure 107. Movements of sauger 48.841 (N=10) during 2003 in the Yellowstone River, Montana.

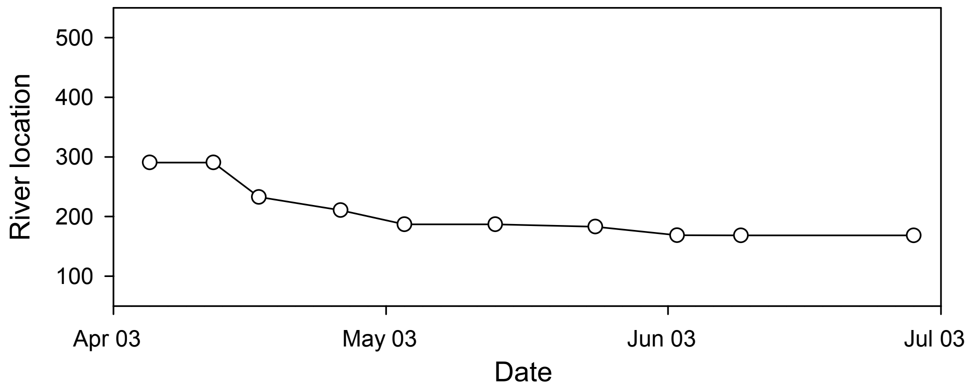


Figure 108. Movements of sauger 48.902 (N=10) during 2003 in the Yellowstone River, Montana.

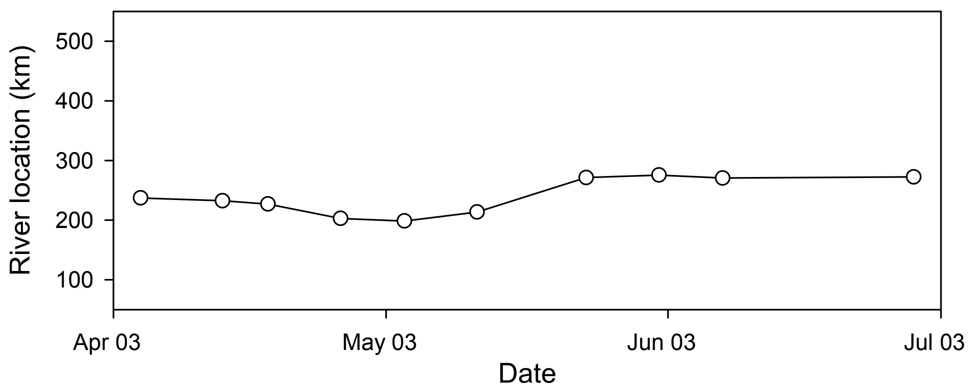
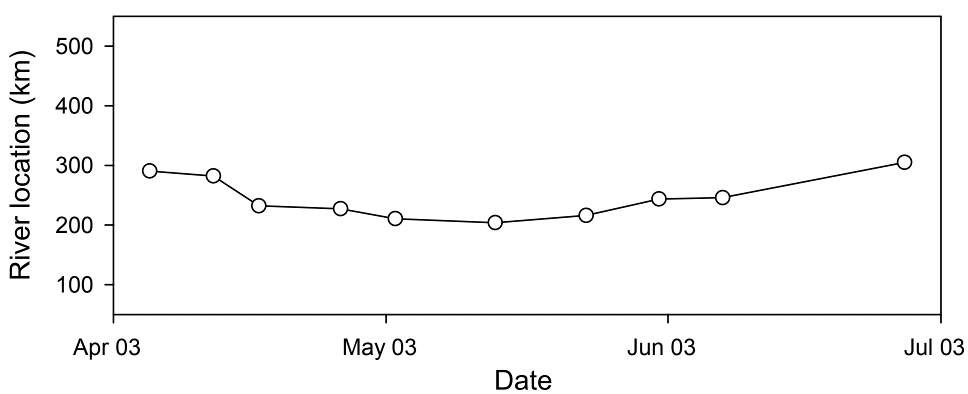


Figure 109. Movements of sauger 48.921 (N=10) during 2003 in the Yellowstone River, Montana.



APPENDIX B

AVAILABILITY AND USE OF RESOURCE UNITS

Table 7. Availability and use by telemetered sauger of resource units in the Yellowstone River, 2001 to 2003. Base flow conditions occur during the spawning, autumn, and winter seasons; run off conditions occur during the movement season.

Resource unit	Base flow availability		Run off availability		Spawning use		Movement use		Autumn use		Winter use	
	%	(km)	%	(km)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)
Geology												
Lance Formation	29.3	(189.8)	30.4	(262.1)	0.0	(0.0)	0.0	(2.3)	27.9	(7.7)	18.0	(7.6)
Bearpaw Shale	10.1	(65.7)	12.8	(111.9)	0.0	(0.0)	1.6	(0.8)	2.3	(1.7)	4.0	(4.0)
Judith River Frmn.	1.3	(8.6)	2.0	(17.5)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hell Creek Frmn.	9.0	(58.3)	8.7	(75.4)	1.4	(0.7)	5.7	(1.8)	9.2	(4.9)	8.0	(4.7)
Tullock Member	25.4	(164.8)	21.9	(188.9)	83.9	(2.6)	65.6	(4.2)	60.5	(8.3)	70.0	(9.1)
Lebo Member	2.9	(18.5)	2.1	(18.5)	8.3	(1.9)	5.0	(1.7)	0.0	(0.0)	0.0	(0.0)
Tongue R. Member	10.2	(66.3)	9.2	(79.3)	4.3	(1.4)	8.0	(2.6)	0.0	(0.0)	0.0	(0.0)
Pierre Shale	4.9	(31.9)	5.3	(45.7)	0.4	(0.3)	2.3	(1.2)	0.0	(0.0)	0.0	(0.0)
Ludlow Member	6.9	(44.7)	7.3	(62.8)	1.7	(0.7)	4.1	(1.9)	0.0	(0.0)	0.0	(0.0)
Habitat												
Scour pool	27.0	(174.9)	20.3	(174.9)	14.1	(2.2)	20.0	(2.9)	25.0	(6.4)	33.3	(8.5)
Bluff pool	11.3	(73.1)	8.5	(73.1)	34.1	(3.6)	11.1	(2.4)	23.4	(7.0)	28.7	(8.3)
Terrace pool	5.8	(37.4)	4.3	(37.4)	45.9	(3.5)	18.3	(3.1)	4.4	(3.2)	8.0	(5.5)
Rip-rap: bottom	9.0	(58.4)	6.8	(58.4)	1.5	(0.5)	4.3	(1.1)	2.6	(1.7)	4.0	(2.8)
Rip-rap: margin	9.6	(62.1)	7.2	(62.1)	1.3	(0.5)	11.4	(2.2)	16.1	(5.6)	26.0	(8.7)
Channel crossover	12.9	(83.6)	9.7	(83.6)	1.4	(0.6)	8.5	(1.6)	8.0	(3.5)	0.0	(0.0)
Secondary channel	24.5	(159.1)	43.2	(372.5)	1.6	(0.7)	26.3	(3.2)	20.3	(6.7)	0.0	(0.0)

Table 8. Availability of habitat units nested within geologic types in the Yellowstone River, 2001 to 2003. Base flow conditions occur during the spawning, autumn, and winter seasons; run off conditions occur during the movement season.

	Habitat Unit													
	Scour pool		Bluff pool		Terrace pool		Rip-rap: bottom		Rip-rap: margin		Channel crossover		Secondary channel	
Geologic Type	%	(km)	%	(km)	%	(km)	%	(km)	%	(km)	%	(km)	%	(km)
							Base flow availability							
Lance Formation	8.9	(57.9)	2.4	(15.7)	0.1	(0.6)	1.6	(10.6)	6.2	(40.4)	8.9	(57.9)	2.4	(15.7)
Bearpaw Shale	3.6	(23.2)	0.7	(4.6)	0.0	(0.0)	2.1	(13.4)	0.2	(1.6)	3.6	(23.2)	0.7	(4.6)
Judith River Frmn.	0.3	(1.7)	0.5	(3.0)	0.0	(0.0)	0.2	(1.4)	0.0	(0.0)	0.3	(1.7)	0.5	(3.0)
Hell Creek Frmn.	2.0	(12.8)	0.7	(4.4)	0.6	(3.9)	1.2	(7.5)	0.6	(4.2)	2.0	(12.8)	0.7	(4.4)
Tullock Member	5.9	(38.0)	3.9	(25.6)	1.9	(12.4)	3.2	(21.0)	2.1	(13.5)	5.9	(38.0)	3.9	(25.6)
Lebo Member	0.4	(2.6)	0.4	(2.8)	1.5	(9.7)	0.0	(0.0)	0.1	(0.7)	0.4	(2.6)	0.4	(2.8)
Tongue R. Member	2.6	(16.6)	0.8	(5.1)	1.1	(7.4)	0.3	(2.2)	0.0	(0.0)	2.6	(16.6)	0.8	(5.1)
Pierre Shale	1.1	(7.3)	0.6	(3.8)	0.2	(1.5)	0.2	(1.0)	0.0	(0.0)	1.1	(7.3)	0.6	(3.8)
Ludlow Member	2.3	(14.9)	1.3	(8.2)	0.3	(2.0)	0.2	(1.2)	0.2	(1.6)	2.3	(14.9)	1.3	(8.2)
							Runoff availability							
Lance Shale	6.7	(57.9)	1.8	(15.7)	0.1	(0.6)	1.2	(10.6)	4.7	(40.4)	1.9	(16.1)	14.0	(120.8)
Bearpaw Shale	2.7	(23.2)	0.5	(4.6)	0.0	(0.0)	1.6	(13.4)	0.2	(1.6)	1.0	(9.0)	7.0	(60.2)
Judith River Shale	0.2	(1.7)	0.3	(3.0)	0.0	(0.0)	0.2	(1.4)	0.0	(0.0)	0.2	(1.5)	1.1	(9.9)
Hell Creek Shale	1.5	(12.8)	0.5	(4.4)	0.5	(3.9)	0.9	(7.5)	0.5	(4.2)	0.9	(7.6)	4.1	(35.0)
Tullock Member	4.4	(38.0)	3.0	(25.6)	1.4	(12.4)	2.4	(21.0)	1.6	(13.5)	2.9	(24.9)	6.2	(53.5)
Lebo Member	0.3	(2.6)	0.3	(2.8)	1.1	(9.7)	0.0	(0.0)	0.1	(0.7)	0.3	(2.7)	0.0	(0.0)
Tongue R. Member	1.9	(16.6)	0.6	(5.1)	0.9	(7.4)	0.3	(2.2)	0.0	(0.0)	1.3	(11.2)	4.3	(36.7)
Pierre Shale	0.8	(7.3)	0.4	(3.8)	0.2	(1.5)	0.1	(1.0)	0.0	(0.0)	0.4	(3.8)	3.3	(28.2)
Ludlow Member	1.7	(14.9)	0.9	(8.2)	0.2	(2.0)	0.1	(1.2)	0.2	(1.6)	0.8	(6.7)	3.3	(28.3)

Table 9. Use of habitat units nested within geologic types during the spawning period by sauger telemetered in the Yellowstone River, 2001 to 2003.

	Spawning Habitat Use														
	Scour pool		Bluff pool		Terrace pool		Rip-rap: bottom		Rip-rap: margin		Channel crossover		Secondary channel	
Geologic Type	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)
Lance Formation	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Bearpaw Shale	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Judith River Frmn.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hell Creek Frmn.	0.7	(0.5)	0.0	(0.0)	0.5	(0.3)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.2	(0.2)
Tullock Member	10.3	(1.9)	33.0	(3.6)	37.6	(3.6)	1.0	(0.5)	1.1	(0.5)	1.1	(0.5)	1.4	(0.7)
Lebo Member	0.2	(0.2)	0.9	(0.6)	6.2	(1.6)	0.5	(0.3)	0.2	(0.2)	0.0	(0.0)	0.0	(0.0)
Tongue R. Member	1.8	(0.7)	0.0	(0.0)	1.1	(0.5)	0.0	(0.0)	0.0	(0.0)	0.4	(0.4)	0.0	(0.0)
Pierre Shale	0.2	(0.2)	0.0	(0.0)	0.2	(0.2)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Ludlow Member	1.2	(0.7)	0.0	(0.0)	0.5	(0.4)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

Table 10. Use of habitat units nested within geologic types during the movement period by sauger telemetered in the Yellowstone River, 2001 to 2003.

	Movement Habitat Use													
	Scour pool		Bluff pool		Terrace pool		Rip-rap: bottom		Rip-rap: margin		Channel crossover		Secondary channel	
Geologic Type	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)
Lance Formation	2.2	(1.3)	1.3	(1.2)	0.0	(0.0)	0.0	(0.0)	1.4	(0.8)	0.0	(0.0)	2.1	(0.9)
Bearpaw Shale	1.0	(0.7)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.1	(0.1)	0.2	(0.2)
Judith River Frmn.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hell Creek Frmn.	0.9	(0.5)	0.0	(0.0)	0.8	(0.6)	0.5	(0.3)	1.8	(0.8)	0.3	(0.3)	2.4	(1.1)
Tullock Member	10.9	(2.1)	8.8	(2.1)	13.5	(2.9)	3.4	(1.0)	7.5	(1.9)	7.5	(1.5)	9.6	(2.0)
Lebo Member	4.4	(1.5)	0.5	(0.3)	2.9	(1.1)	0.5	(0.5)	0.6	(0.4)	0.6	(0.6)	0.0	(0.0)
Tongue R. Member	2.6	(1.5)	0.2	(0.2)	0.7	(0.4)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	4.5	(2.1)
Pierre Shale	0.3	(0.3)	0.0	(0.0)	0.4	(0.4)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	1.6	(0.9)
Ludlow Member	2.2	(1.3)	0.3	(0.3)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	1.6	(1.2)

Table 11. Use of habitat units nested within geologic types during the autumn period by sauger telemetered in the Yellowstone River, 2001 to 2003.

	Autumn Habitat Use													
	Scour pool		Bluff pool		Terrace pool		Rip-rap: bottom		Rip-rap: margin		Channel crossover		Secondary channel	
Geologic Type	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)
Lance Formation	7.4	(4.3)	5.9	(4.1)	0.0	(0.0)	0.0	(0.0)	5.9	(4.1)	2.9	(2.9)	5.9	(4.1)
Bearpaw Shale	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	2.3	(1.7)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Judith River Frmn.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hell Creek Frmn.	0.7	(0.7)	0.0	(0.0)	0.0	(0.0)	1.2	(0.8)	4.0	(2.9)	0.4	(0.4)	2.9	(2.9)
Tullock Member	17.0	(5.6)	17.5	(6.2)	4.4	(3.2)	0.0	(0.0)	5.4	(3.3)	4.7	(2.1)	11.5	(5.2)
Lebo Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Tongue R. Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Pierre Shale	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Ludlow Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

Table 12. Use of habitat units nested within geologic types during the winter period by sauger telemetered in the Yellowstone River, 2001 to 2003.

	Winter Habitat Use													
	Scour pool		Bluff pool		Terrace pool		Rip-rap: bottom		Rip-rap: margin		Channel crossover		Secondary channel	
Geologic Type	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)	Mean %	(SE)
Lance Formation	10.0	(5.8)	8.0	(5.5)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Bearpaw Shale	2.0	(2.0)	2.0	(2.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Judith River Frmn.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Hell Creek Frmn.	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	4.0	(2.8)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Tullock Member	21.3	(7.6)	18.7	(7.2)	8.0	(5.5)	0.0	(0.0)	26.0	(8.7)	0.0	(0.0)	0.0	(0.0)
Lebo Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Tongue R. Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Pierre Shale	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Ludlow Member	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)

APPENDIX C

SPATIAL ASSOCIATIONS

Table 13. Spatial scale (km) of weekly distribution patterns as determined by Ripley's K analysis (*P* < 0.10) of telemetered sauger in the lower Yellowstone River April 2001 to July 2003.

Date	Aggregated distribution	Random distribution	Segregated distribution
15-Apr-2001	0-13.5	14-23	23.5-57
20-Apr-2001	0-12	12.5-23.5	24-59.5
26-Apr-2001	0-12.5	13-43, 58.5-69.5	43.5-58, 70-88
4-May-2001	0-9	9.5-113.5	114-119.5
18-May-2001	0-4, 28-82.5	4.5-27.5, 83-174	175.165.5
25-May-2001	63.5-104.5, 122.5-142.5	0-63, 105-122, 143-245.5	246-250
2-Jun-2001		0-238	238.5-264
14-Jun-2001	0-7.5, 22.5-26	8.5-22, 26.5-258.5	259-265.5
30-Jun-2001		0-283.5	284-294.5
13-Jul-2001		0-283.5	284-294.5
27-Jul-2001		0-268	268.5-292.5
24-Aug-2001		0-268	268.5-292.5
7-Sep-2001	0-6	6.5-27, 37-206	27.5-36.5, 206.5-221
22-Sep-2001	0-6	6.5-27, 37-206	27.5-36.5, 206.5-221

Table 13. (*cont.*)

5-Oct-2001	0-4	4.5-116	116.5-122.5
19-Oct-2001	0-6	6.5-26	26.5-40.5
1-Nov-2001	0-6	6.5-70.5	71-123
23-Feb-2002	0-1	1.5-156, 180.5-194.5, 217.5-229.5	156.5-180, 195-217, 230-248
13-Apr-2002	0-15.5	16-31.5, 57-70	32-56.5, 70.5-116
20-Apr-2002	0-16.5	17-41, 56-87.5, 114-120	41.5-55.5, 88-113.5, 120.5-126.5
26-Apr-2002	0-23.5	24-44, 55.5-90.5	44.5-55, 91-129
3-May-2002	0-44	44.5-89	89.5-93
11-May-2002	0-191.5	192-229.5	230-235
17-May-2002	0-101.5, 127-134, 155-171	102-126.5, 134.5-154.5, 171.5-262	262.5-273
24-May-2002	0-22, 46-173.5, 212.5-216.5	22.5-45.5, 174-212, 217-286.5	287-293.5
31-May-2002	0-26.5, 57-64.5	27-56.5, 65-254	254.5-265
7-Jun-2002	34-45	0-33.5, 45.5-288.5	289-292.5
14-Jun-2002	0-2	2.5-275.5	276-280
21-Jun-2002	0-151, 242.5-250.5	151.5-242, 251-330	330.5-340.5
28-Jun-2002	0-10	10.5-270.5, 275-279.5	271-274.5, 280-284

Table 13. (*cont.*)

12-Jul-2002		0-45, 68.5-109, 111.5-113.5, 130.5-140.5	45.5-68, 109.5-111, 114-129.5, 141-143.5
26-Jul-2002	0-47, 65-134	47.5-64.5, 134.5-279	279.5-283.5
9-Aug-2002		0-72	72.5-77
24-Aug-2002	0-3.5, 23-39.5, 78-137	4-22.5, 40-77.5, 137.5-221	221.5-225.5
6-Sep-2002	0-3	3.5-212	212.5-216.5
20-Sep-2002		0-221.5	222-225
5-Oct-2002		0-151	151.5-155.5
18-Oct-2002		0-220.5	221-225.5
2-Dec-2002		0-197.5	198-218
24-Feb-2003		0-204	204.5-220.5
28-Mar-2003		0-127	127.5-132.5
10-Apr-2003	0-19.5	20-27.5, 58-60, 67-72	28-57.5, 60.5-66.5, 72.5-77.5
17-Apr-2003	0-37	37.5-85.5	86-89.5
25-Apr-2003	0-93.5	94-115.5	
2-May-2003	0-112.5	113-146	
10-May-2003	0-21.5, 34-65.5, 77.5-104.5, 114.5-138	22-33.5, 66-77, 105-114, 139-213.5	

Table 13. (*cont.*)

23-May-2003	0-14, 31.5-117, 124-162	14.5-31, 117.5-123.5, 162.5-242.5	
31-May-2003	0-1.5, 9-46, 80-104	2-8.5, 46.5-79.5, 104.5-219.5	
7-Jun-2003	0-223.5	224-276.5	
27-Jun-2003	55.5-57, 60.5-100, 120.5-130.5	0-55, 57.5-60, 100.5-120, 131-300	300.5-304.5

APPENDIX D

MODEL OUTPUT

Table 14. Annual tagging results for sauger in the Yellowstone River above Intake Diversion, 2001 to 2003. Returns refer to the number fish harvested; returns in parentheses refer to the total number of fish caught.

Year tagged	Number tagged	Returns		
		2001	2002	2003
2001	199	7 (21)	11 (15)	3 (8)
2002	332		25 (35)	20 (25)
2003	295			25 (41)

Table 15. Seasonal tagging results for sauger in the Yellowstone River above Intake Diversion, 2001 to 2003. Returns refer to the number fish harvested; returns in parentheses refer to the total number of fish caught.

Year tagged	Season tagged	Number tagged	Returns					
			Spring 2001	Autumn 2001	Spring 2002	Autumn 2002	Spring 2003	Autumn 2003
2001	Spring	168	2 (10)	3 (4)	1 (1)	6 (9)	0 (2)	2 (3)
	Autumn	31		2 (7)	0 (1)	4 (4)	0 (1)	1 (2)
2002	Spring	205			4 (10)	15 (16)	1 (2)	9 (11)
	Autumn	127				6 (8)	1 (2)	9 (11)
2003	Spring	183					1 (4)	7 (10)
	Autumn	112						17 (27)

Table 16. Model output for candidate models used to estimate annual survival and probability of being caught of sauger on the Yellowstone River, 2001 to 2003. Models tested were constant annual survival and probability of capture (S(.)f(.)), constant survival and time dependant probability of capture (S(.)f(t)), time dependant survival and constant probability of capture (S(t)f(.)), and time dependant survival and probability of capture (S(t)f(t)).

Model	AICc	Δ AICc	AICc weight	# of parameters	deviance
S(.)f(.)	617.52	0.00	0.52	2	3.15
S(.)f(t)	619.51	1.98	0.19	4	1.04
S(t)f(.)	679.56	2.04	0.19	3	3.14
S(t)f(t)	620.86	3.33	0.10	5	0.33

Table 17. Model output for candidate models used to estimate annual probability of being harvested of sauger on the Yellowstone River, 2001 to 2003. Models tested were constant annual survival and probability of harvest (S(.)f(.)), constant survival and time dependant probability of harvest (S(.)f(t)), time dependant survival and constant probability of harvest (S(t)f(.)), and time dependant survival and probability of harvest (S(t)f(t)). Overdispersion was adjusted for and model selection is based on c-hat = 3.12.

Model	QAICc	Δ QAICc	QAICc weight	# of parameters	deviance
S(.)f(.)	163.24	0.00	0.46	2	3.69
S(.)f(t)	164.77	1.53	0.23	4	1.12
S(t)f(.)	164.96	1.72	0.21	3	3.37
S(t)f(t)	166.78	3.53	0.08	5	1.07

Table 18. Model output for candidate models used to estimate apparent seasonal survival of sauger on the Yellowstone River, 2001 and 2002. Models tested were constant seasonal survival (S(.)) and time dependant seasonal survival (S(t).

Model	AICc	Δ AICc	AICc weight	# of parameters	deviance
			2001		
S(.)	67.99	0.00	0.86	1	0.72
S(t)	71.59	3.60	0.14	3	0.00
			2002		
S(.)	77.12	0.00	0.76	1	2.00
S(t)	79.40	2.28	0.24	3	0.00

Table 19. Model output for candidate models used to estimate seasonal probability of being caught of sauger on the Yellowstone River, 2001 to 2003. Models tested were constant seasonal survival and probability of capture (S(.)f(.)), constant survival and time dependant probability of capture (S(.)f(t)), time dependant survival and constant probability of capture (S(t)f(.)), and time dependant survival and probability of capture (S(t)f(t)).

Model	AICc	Δ AICc	AICc weight	# of parameters	deviance
S(t)f(t)	709.02	0.00	1.00	11	19.14
S(.)f(t)	738.63	29.61	0.00	7	57.25
S(t)f(.)	779.98	70.97	0.00	6	100.70
S(.)f(.)	793.37	84.35	0.00	2	122.31

Table 20. Model output for candidate models used to estimate seasonal probability of being harvested of sauger on the Yellowstone River, 2001 to 2003. Models tested were constant seasonal survival and probability of harvest (S(.)f(.)), constant survival and time dependant probability of harvest (S(.)f(t)), time dependant survival and constant probability of harvest (S(t)f(.)), and time dependant survival and probability of harvest (S(t)f(t)).

Model	AICc	Δ AICc	AICc weight	# of parameters	deviance
S(t)f(t)	538.65	0.00	0.93	11	7.52
S(.)f(t)	543.76	5.11	0.07	7	21.13
S(t)f(.)	599.57	60.93	0.00	6	79.04
S(.)f(.)	608.53	69.88	0.00	2	96.22